Rapid Refresh Review – Hourly Updated Models

NCEP Production Suite Review - 2011

NOAA/ESRL/GSD/AMB

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Major topics:

- Rapid Refresh
  - NCEP implementation planned 24 Jan 11
  - significant improvement over RUC
  - major improvements in testing at ESRL for Rapid Refresh 2 (satellite, cloud, soil assimilation, WRFv3.3.1+)

- 3km HRRR @ESRL
  - April 2011 - parent assimilation switched to ESRL Rapid Refresh from ESRL-RUC
  - 2012 – improved surface/soil/cloud assimilation in ESRL-Rapid Refresh, upper boundary, revised radar assim

Wed 7 Dec 2011

NCEP

Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP

Hourly Updated NOAA NWP Models

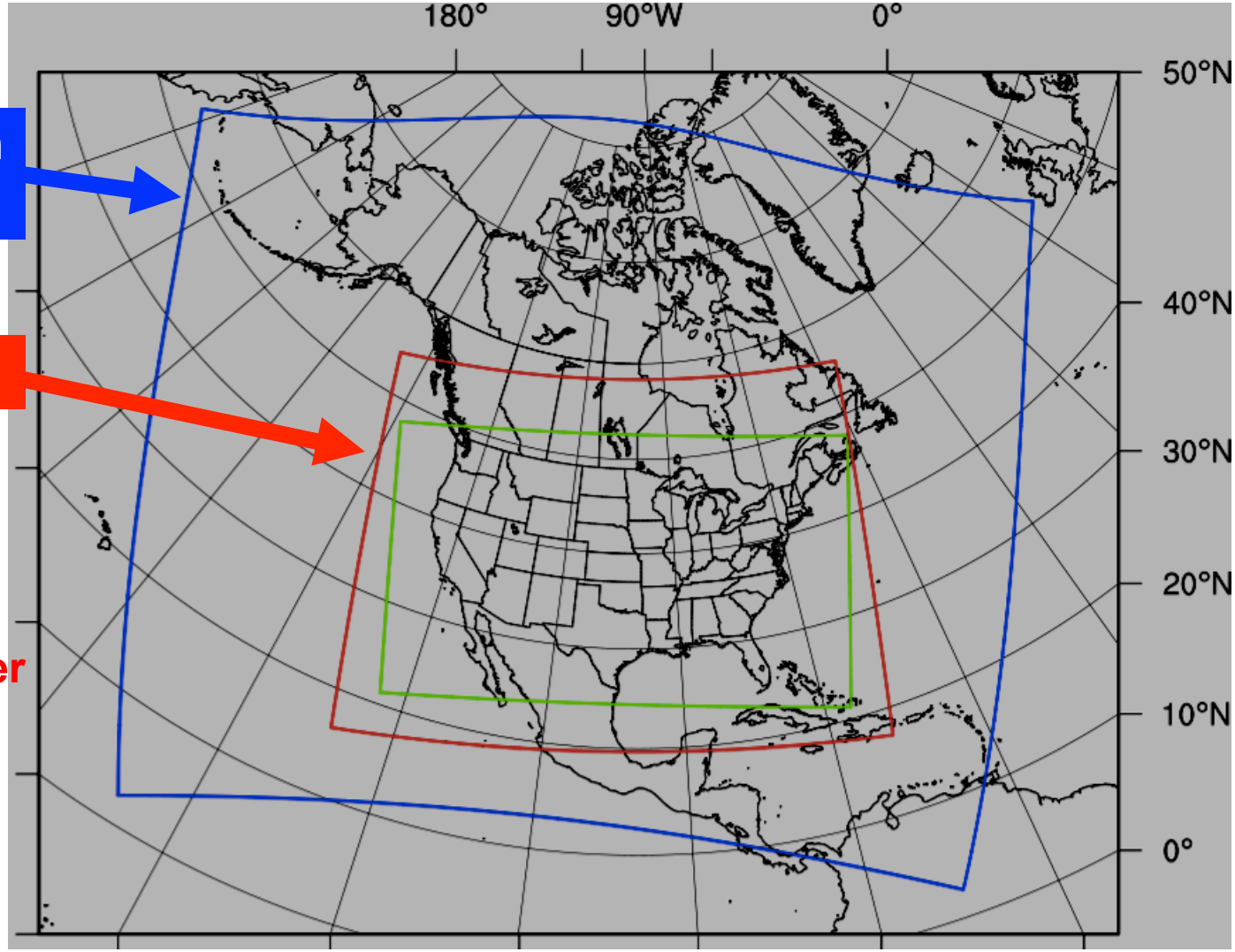
Rapid Refresh (RR)

replaces RUC at NCEP

WRF, GSI with RUC features

13km Rapid Refresh

13km RUC



RUC – current oper model, new 18h fcst every hour

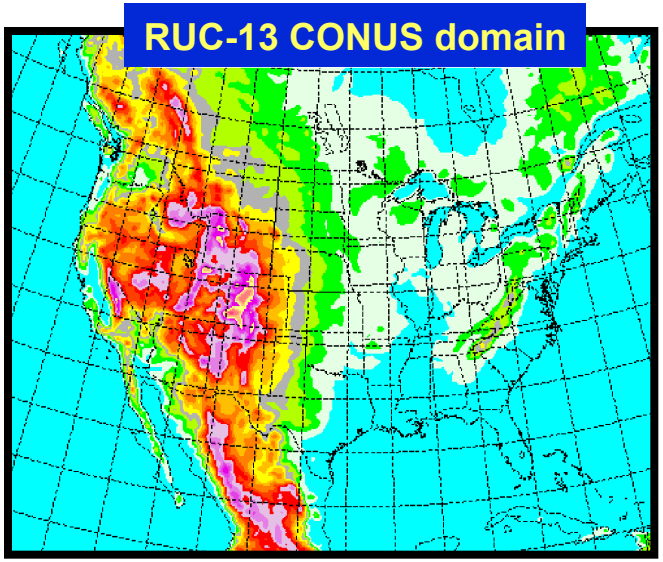
RUC Becomes Rapid Refresh

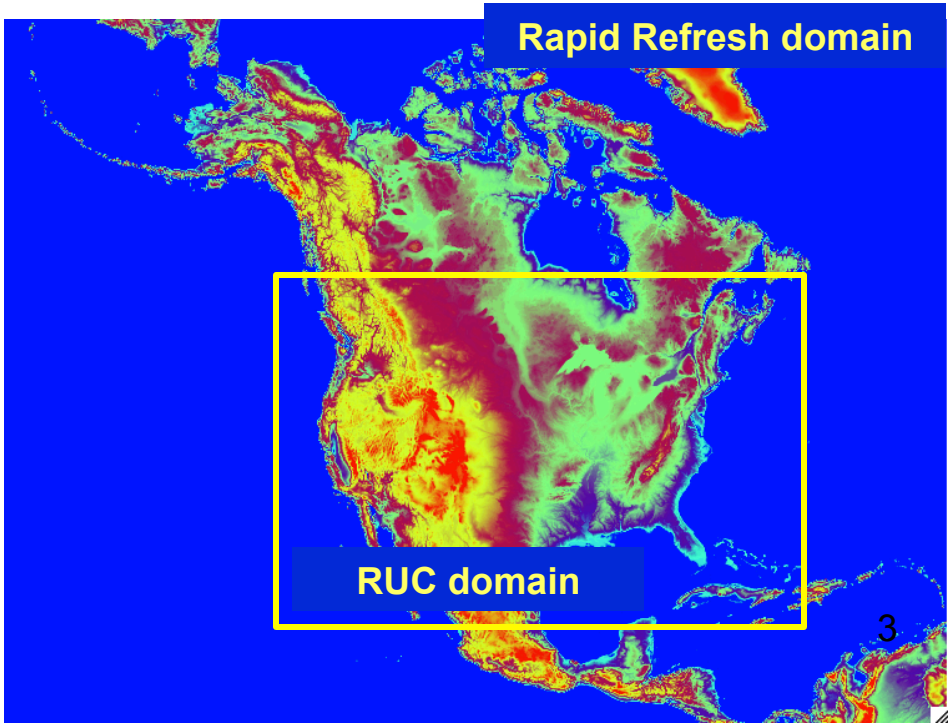
RUC

- Non-WRF RUC model
- RUC 3DVAR analysis
- 24/Day = hourly update
- Forecasts to 18 hours
- 13 km horizontal

Rapid Refresh

- WRF-based ARW
- GSI analysis
- Expanded 13 km Domain
  - ~2.8 times bigger
  - Includes Alaska
- Experimental 3 km HRRR runs ONLY at ESRL currently





Outline

- Model description for Rapid Refresh
- Data assimilation description for RR (RAP)
- Output from RAP (grids, Unipost mods, RTMA, BUFR)
- Partial cycling for Rapid Refresh, SST, land-surface grids
- Verification statistics for RAP vs. RUC

WRF model enhancements for Rapid Refresh

- WRF - ARW - v3.2.1+ for initial RR
  - WRF v3.3 issued too late in April 2011 – NCEP code freeze
- Benefited from ongoing community improvements to WRF
- GSD improvements –
  - Digital filter initialization (DFI - allows quiet 1h forecasts)
  - DFI-radar
  - Grell 3-d cumulus
  - RUC LSM (now with snow LSM cycling on sea ice)
- Use of rotated lat-lon grid - GSD was first to use ARW with RLL

NOAA Hourly Models

Model	Domain	Grid Points	Projection	Grid Spacing	Vertical Levels	Vertical Coordinate	Height of Lowest Level	Pressure Top
RUC	CONUS	451 x 337	Lambert conformal	13 km	50	Sigma/ Isentropic	5 m	40-85 hPa (500K)
RAP	North America	758 x 567	Rotated lat/lon	13 km	50	Sigma	8 m	10 hPa

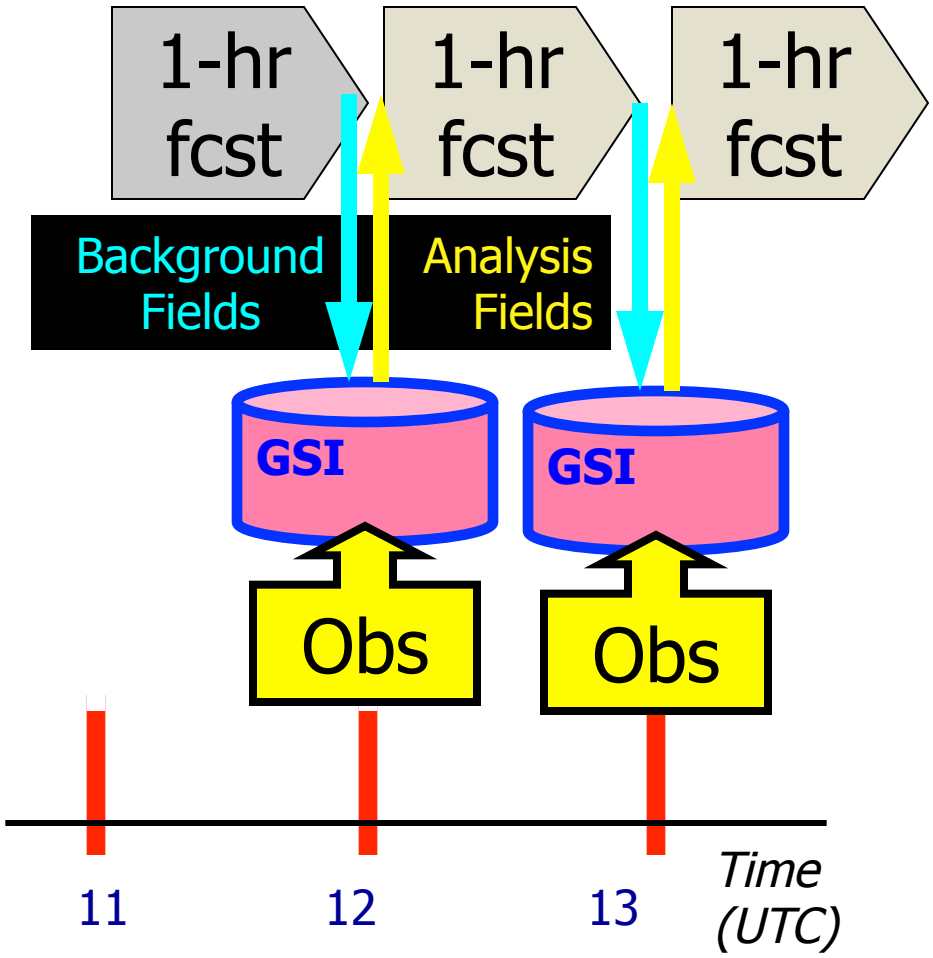
Model	Run at:	Time-Step	Forecast Length	Initialized	Boundary Conditions	Run Time
RUC	**NCEP oper**	18 s	18 hrs	Hourly (cycled)	NAM	~25 min
RAP	**GSD, EMC**	60 s	18 hrs	Hourly (cycled)	GFS	~25 min

Model physics comparison

model	Shortwave Radiation	Cloud physics (# hydrometeor types)	Cumulus parm	Boundary layer (PBL)	Shallow cumulus	Land-surface model
GFS	RRTM	Zhao-Carr (1)	Simplified Arakawa-Schubert	MRF – Troen-Mahrt	Jongil Han	Noah
NAM	Goddard	Ferrier (1)	Betts-Miller-Janjic	Mellor-Yamada-Janjic	BMJ	Noah
RUC	Dudhia	Thompson - 2004 - 1-moment rain (4)	Grell-Devenyi	Burk-Thompson	none	RUC (2003)
Rapid Refresh	Goddard	Thompson - 2010 – 2-moment rain (5)	Grell-3D	Mellor-Yamada-Janjic	Grell	RUC – from WRFv3.3

Rapid Refresh GSI-based Hourly Assimilation Cycle

Cycle hydrometeor, soil temp/moisture/snow



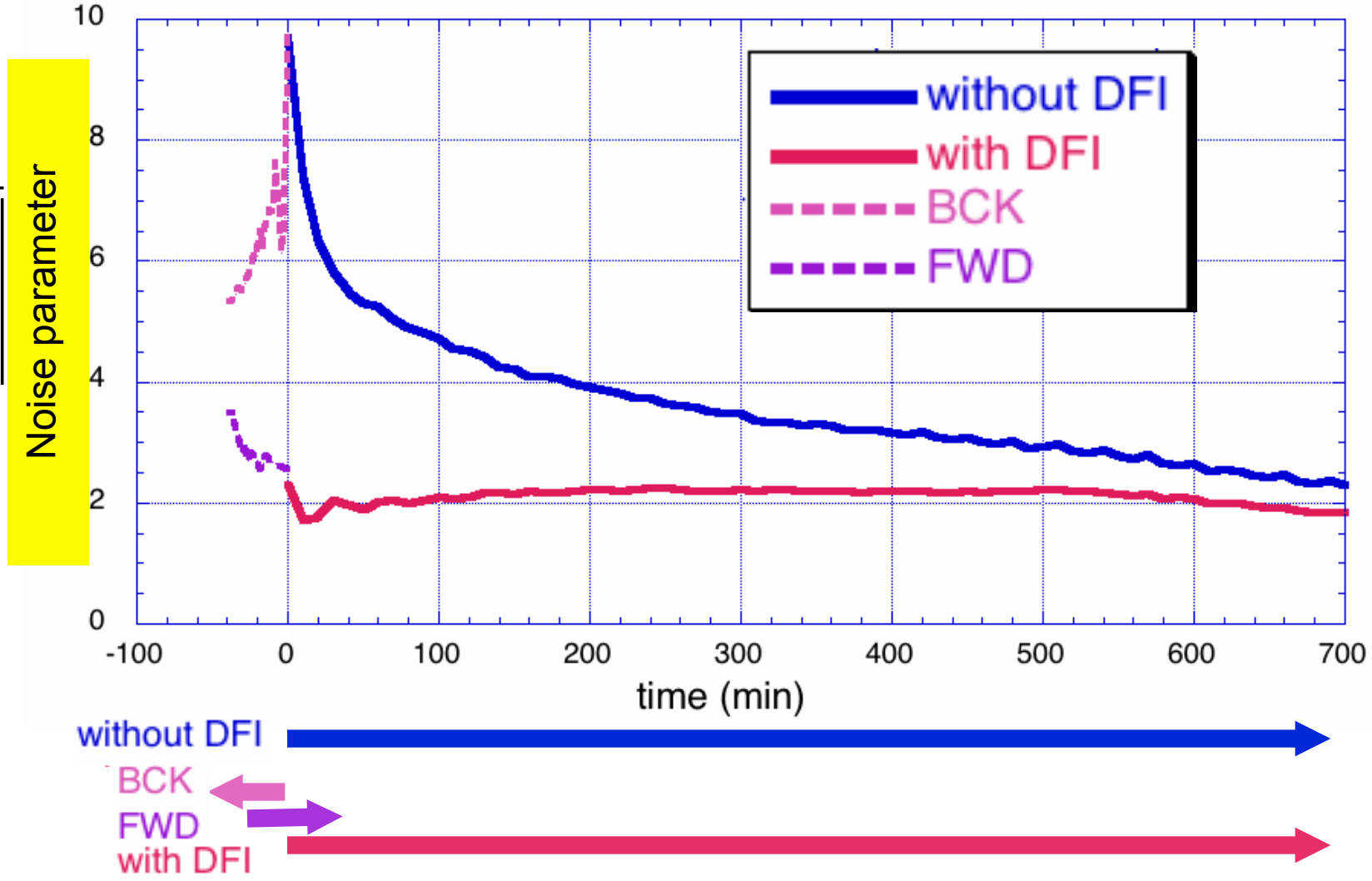
Hourly obs

Data Type	~Number/hr
Rawinsonde (12h)	120
NOAA profilers	21
VAD winds	~125
PBL – profiler/RASS	~25
Aircraft (V,temp)	2K-15K(avg 7K)
WVSS (RH)	0-800(avg 520)
Surface/METAR	~2500
Buoy/ship	200-400
GOES cloud winds	4000-8000
GOES cloud-top pres	10 km res
GPS precip water	~260
Mesonet (temp, dpt)	~8000 (RRv2)
Mesonet (wind)	~4000 (RRv2)
METAR-cloud-vis-wx	~2000
AMSU-A/B/HIRS/etc. radiances	
GOES radiances	*- in testing – RRv2*
Radar reflectivity	1km
Lightning (proxy refl)	(RRv2)
Radar radial wind	*- in testing* - RRv2
Nacelle/tower/sodar	(future)

Diabatic Digital Filter Initialization

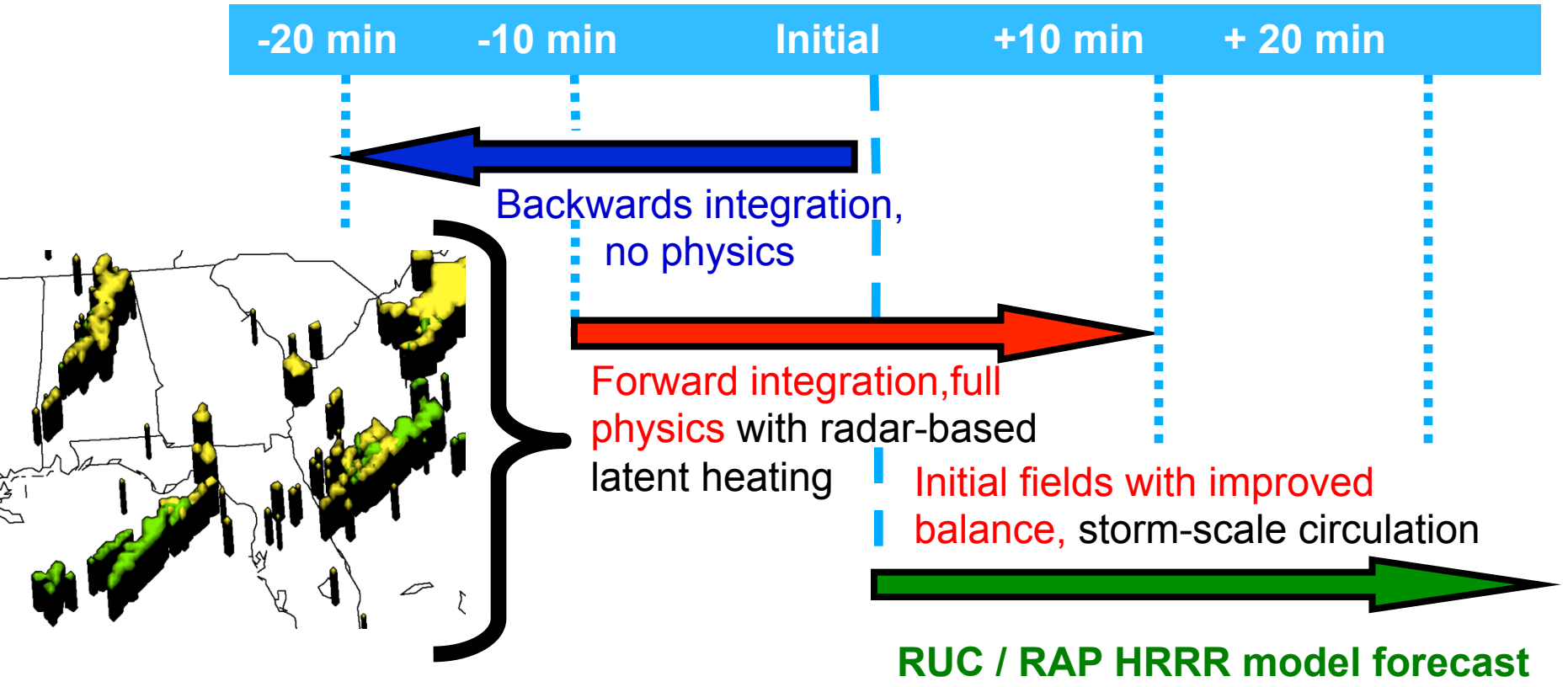
Reduce noise in RUC and Rapid Refresh

$$\left| \frac{\partial p_{sfc}}{\partial t} \right|$$



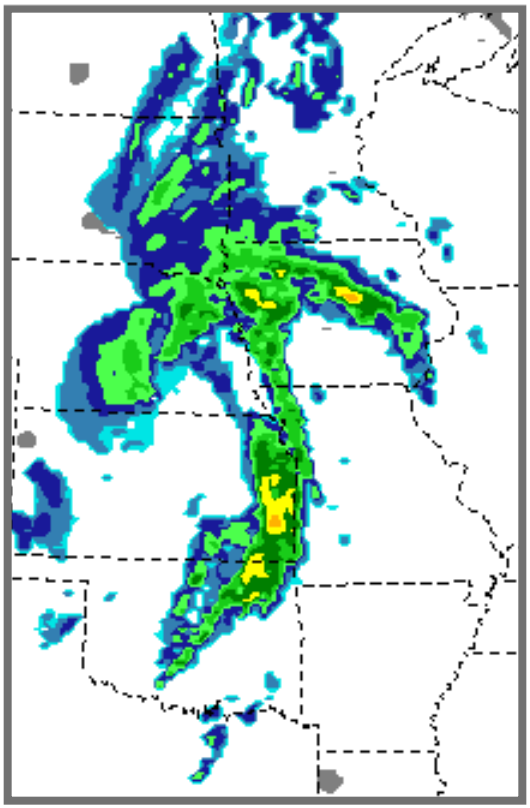
Radar reflectivity assimilation

Digital Filter-based reflectivity assimilation initializes ongoing precipitation regions



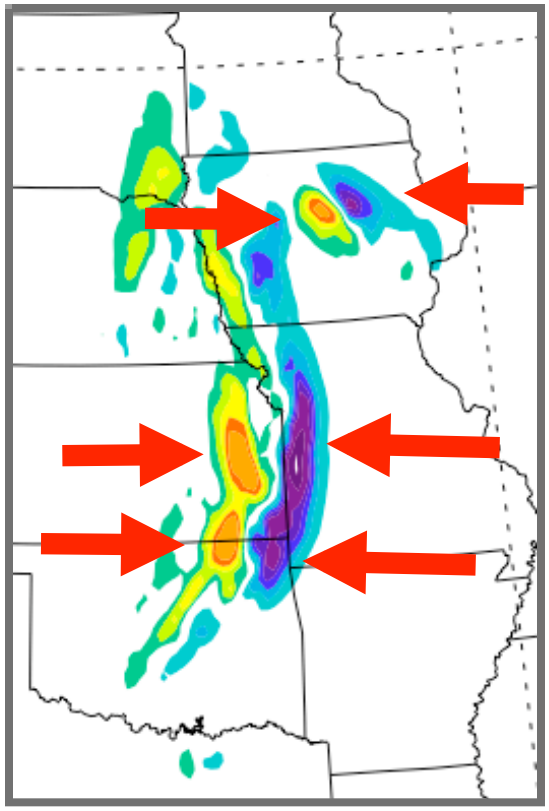
Rapid Refresh (GSI + ARW)
reflectivity assimilation example

NSSL radar reflectivity (dBZ)



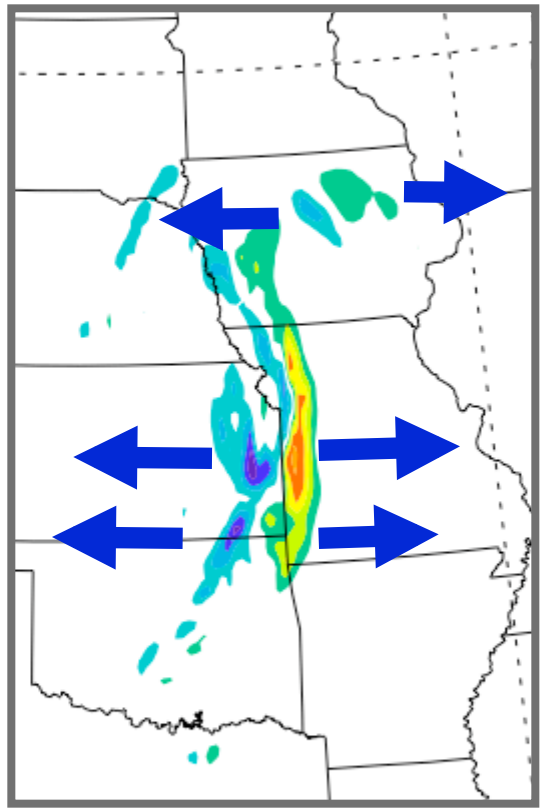
14z 22 Oct 2008
Z = 3 km

Low-level Convergence

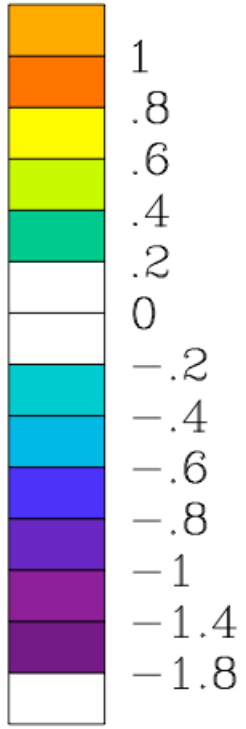


K=4 U-comp. diff
(radar - norad)

Upper-level Divergence



K=17 U-comp. diff
(radar - norad)



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Rapid Refresh
NCEP planned grid distribution

RAP grid distribution from NCEP will include:

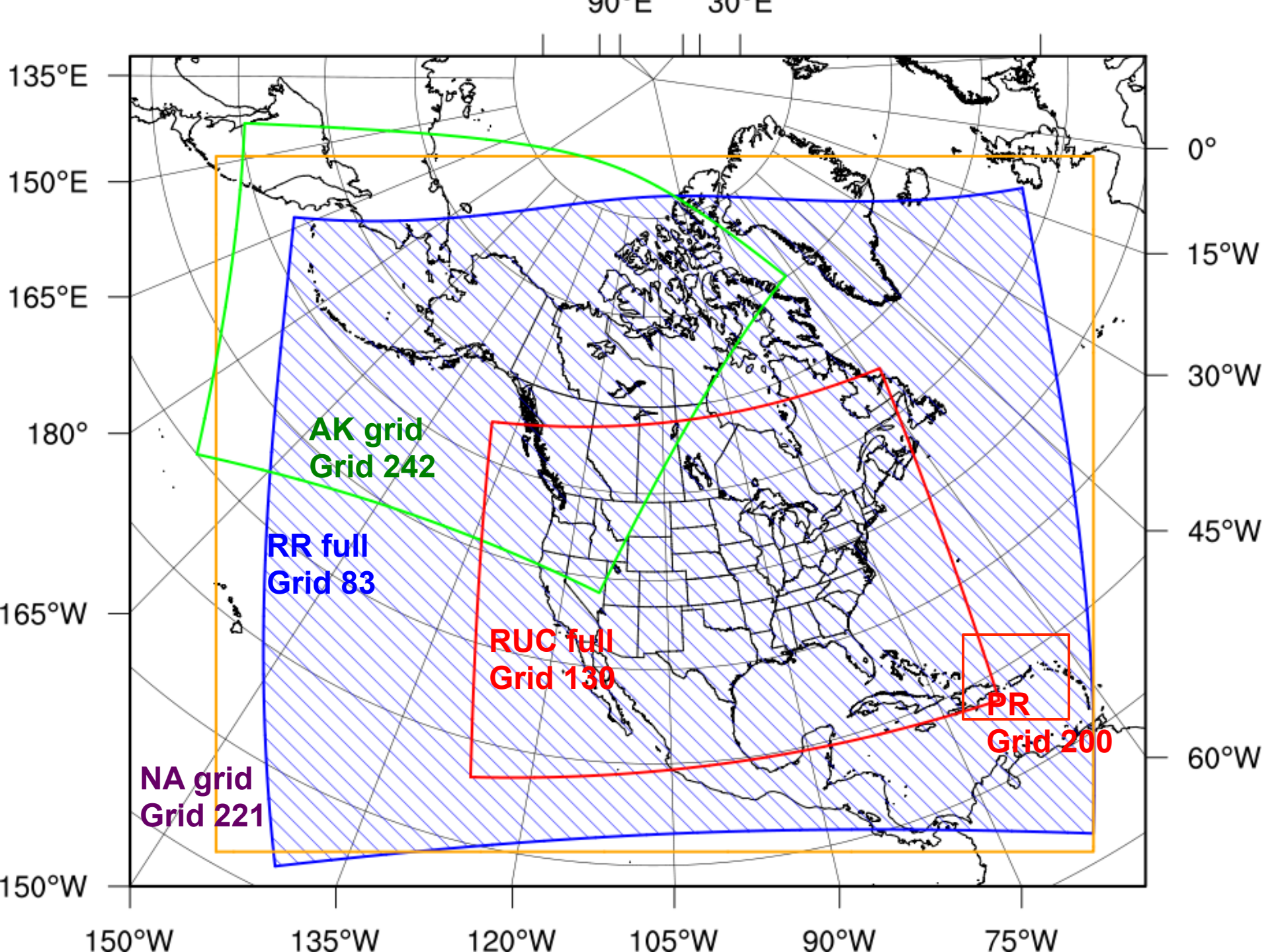
- **130 (13 km CONUS): pgrb, bgrb**
- **252 (20 km CONUS): pgrb, bgrb**
- **236 (40 km CONUS): pgrb**
- **242 (11 km Alaska): one file with all needed parameters**
- **221 (32 km nearly full domain): one file with all needed parameters**

  (NOTE: Full NAM grid is also on 221 grid)

- 200 (12km Puerto Rico) - single output file

Additional grid not to be distributed initially due to bandwidth limitation

- 83 (13km full Rapid Refresh domain on rotated lat/lon grid)


90°E
30°E
135°E
150°E
165°E
180°
165°W
150°W
0°
15°W
30°W
45°W
60°W
150°W
135°W
120°W
105°W
90°W
75°W
AK grid
Grid 242
RR full
Grid 83
RUC full
Grid 130
PR
Grid 200
NA grid
Grid 221

Unipost options added for Rapid Refresh application

- **Ceiling** -includes NCAR code for effect of falling snow
- **Visibility** -includes RH component and updated coefficients from NCAR
  - Now used by Binbin Zhou for SREF
- **MAPS SLP reduction** – more coherent SLP pattern over elevated terrain, matches RUC output SLP
- **Precip-type** – based on explicit qi/qc/qr/qs/qg
- **Heights** for ARW input
- Switch to virtual temp for CAPE/CIN, others
- All commits into NCEP Unipost repository

Other post-processing, NARRE-TL

- **BUFR soundings**
- **Downscaling for RTMA background**
  - RAP replacing RUC
- **GEMPAK grids**
  - for SPC, AWC, HPC
- **Hourly updated regional ensemble** with RAP and NAM time-lagged ensemble members
  - Formerly known as VSREF (very short range)
  - Official name – **NARRE-TL** – *N. American Rapid Refresh Ensemble – Time-lagged*

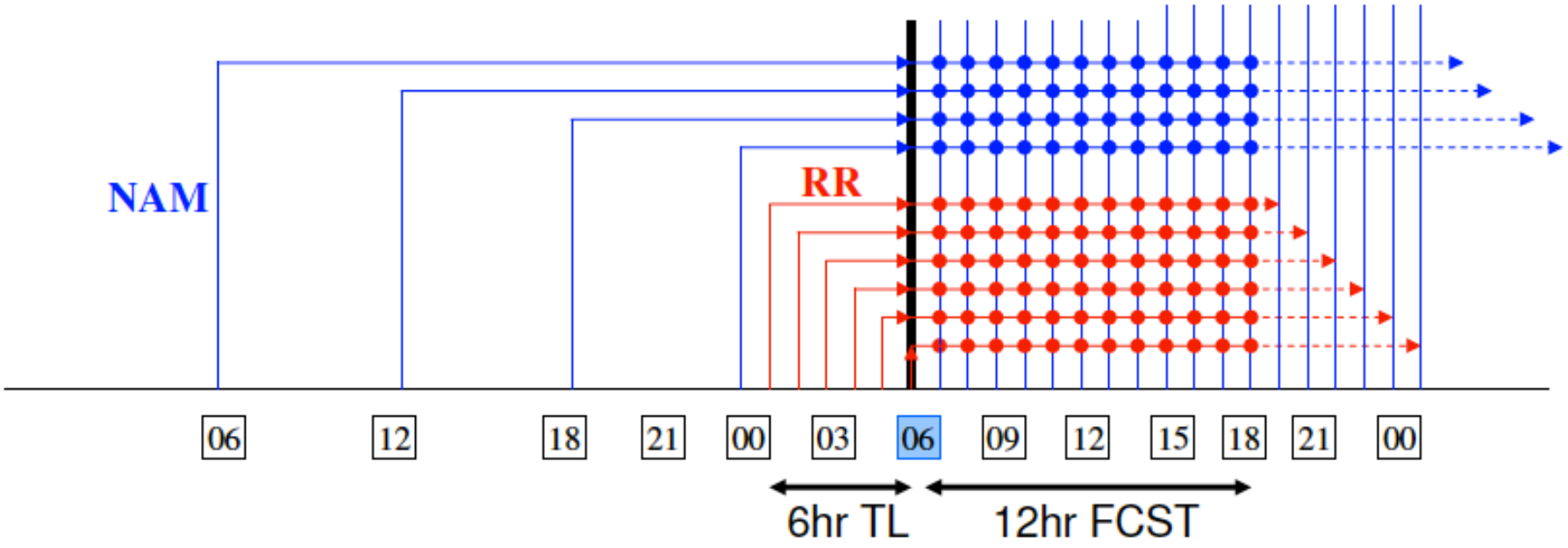
***Member Weighting** = 1 - forecast age (hr)/30*:

1 for current fcst and 0 for 30hr-old fcst

(NAM always older than RR → gives more weight to RR members)

RR's first 6 hr forecasts are used up for time-lag

Example for 06Z cycle's NARRE-TL:



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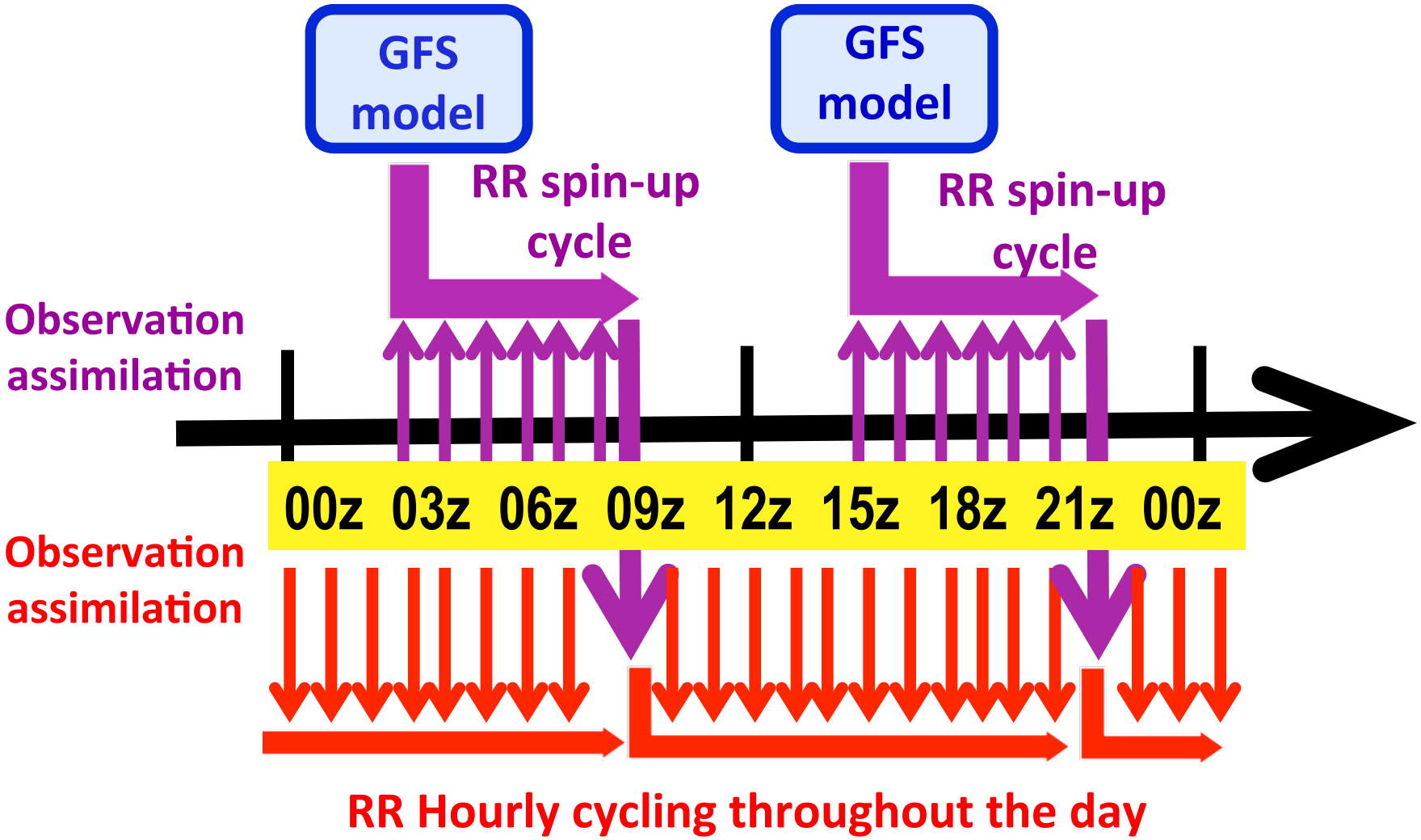
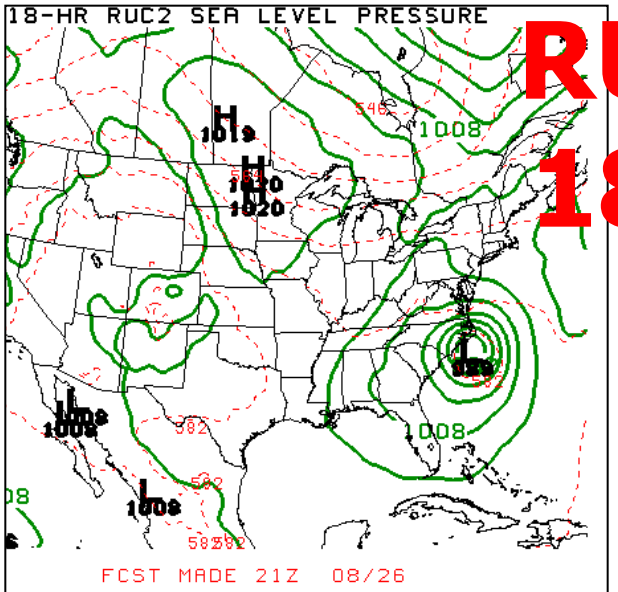
- Verification statistics for RAP vs. RUC

Rapid Refresh Partial Cycling

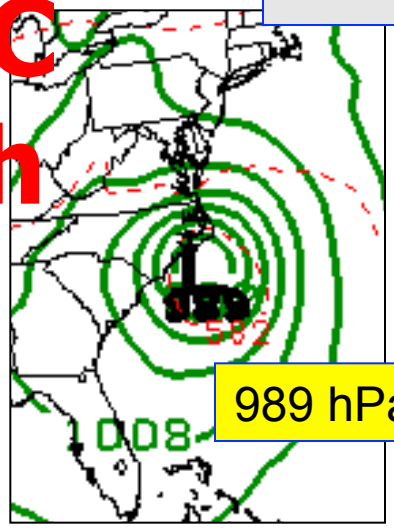


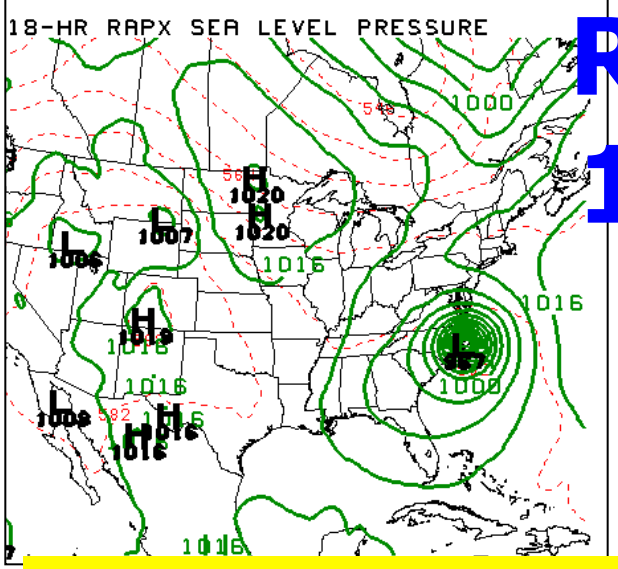
- Hourly cycling of land surface model fields
- 6 hour spin-up cycle for hydrometeors, surface fields

Hurricane Irene

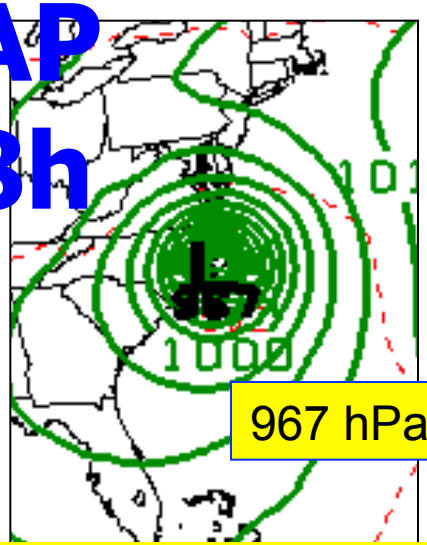


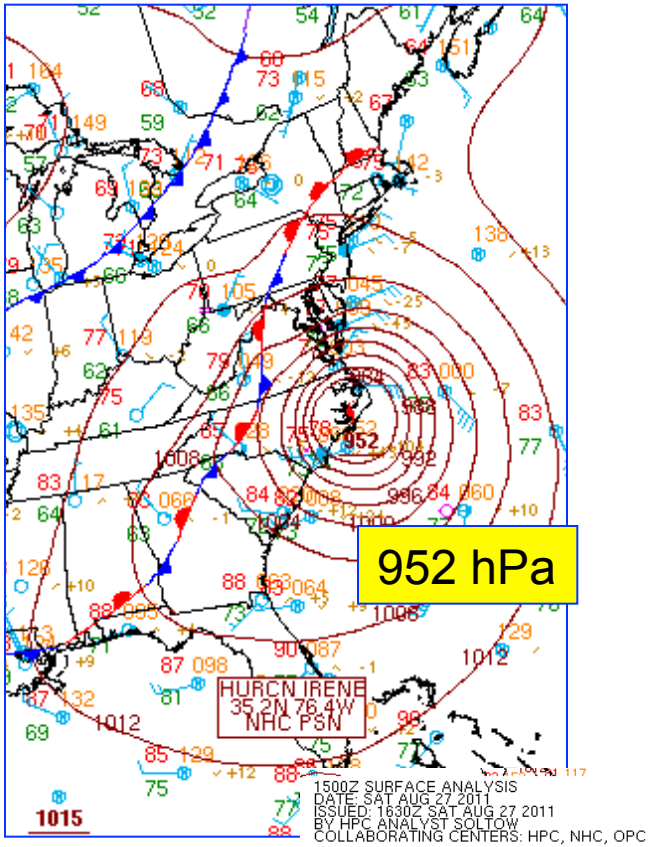
RUC 18h





RAP 18h





Obs

15z Sat 27 Aug 2011

- **RAP partial cycling with GFS inserted 2x/day very helpful for tropical cyclones in RAP, which then spins down TCs to 13km horizontal resolution.**
- **RAP will be much better background for RTMA for TCs**

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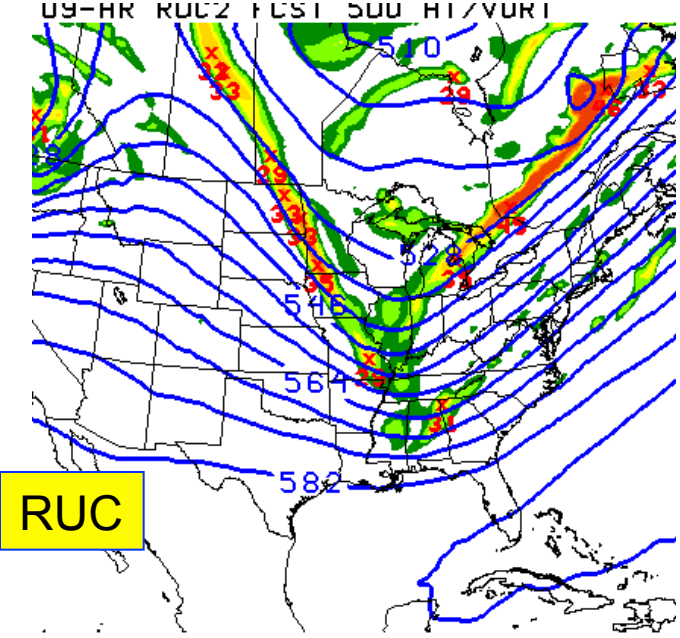
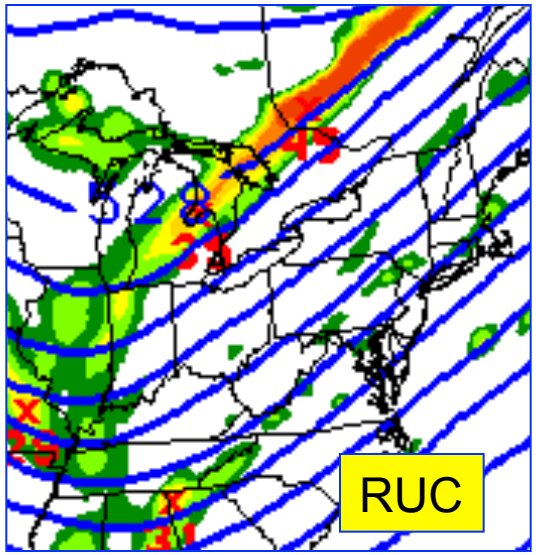
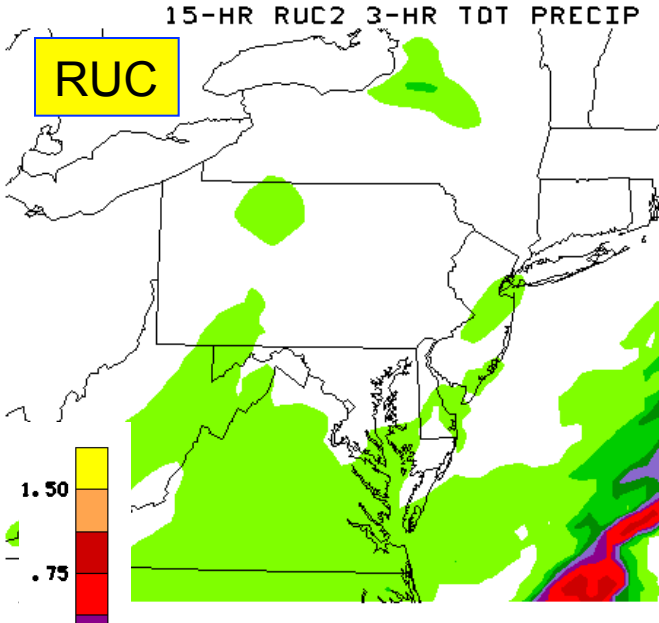
- Case studies and verification statistics for RAP vs. RUC

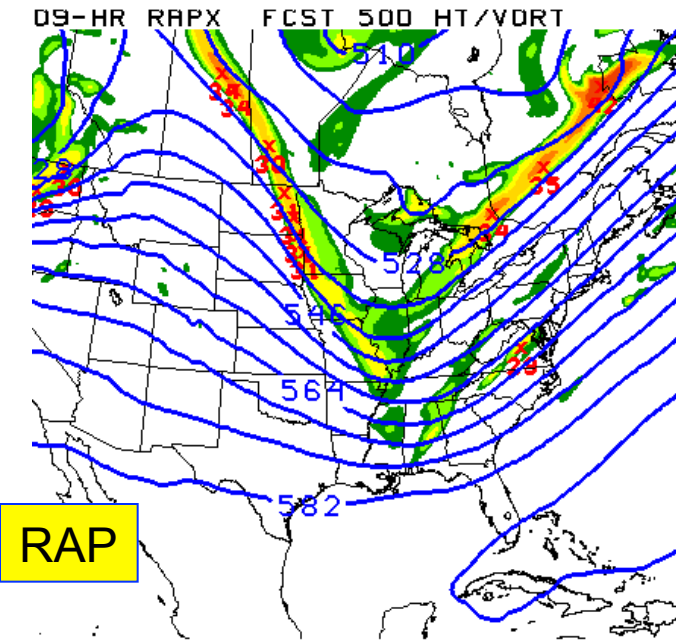
mid-Atlantic post-frontal rain band - evening 16 Nov 2011

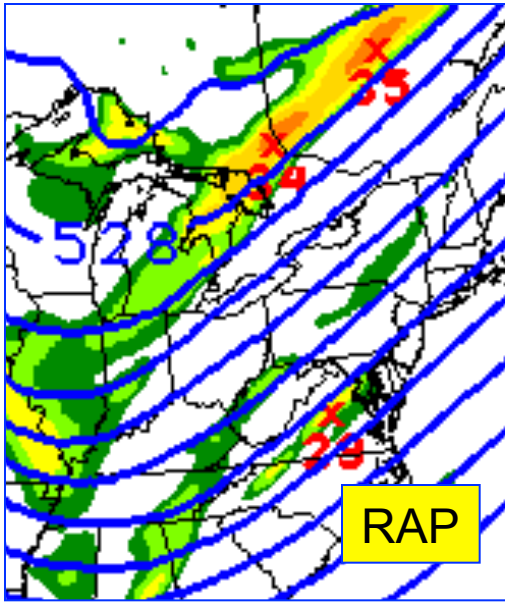
- RAP handled vort max much better, so it had stronger forcing than the RUC in the mid-Atlantic and showed better potential for a rain band behind the sfc cold front

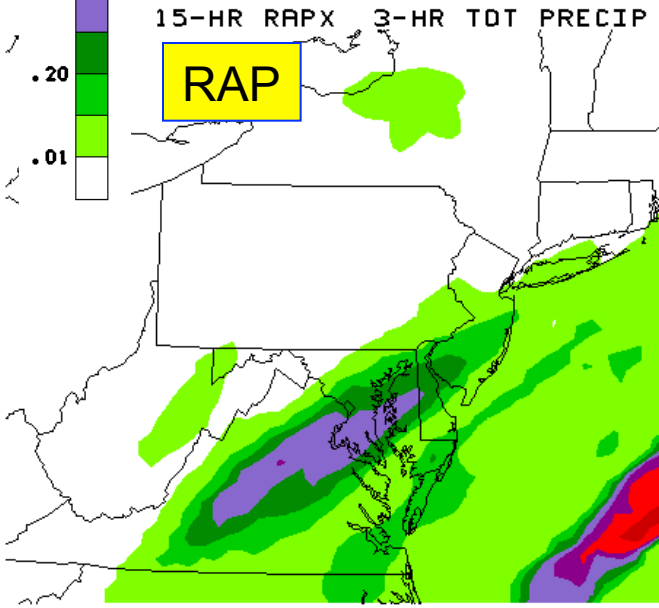

09-HR RUC2 FCST 500 HT/VORT
510
528
546
564
582
RUC
FCST MADE 02Z 11/17

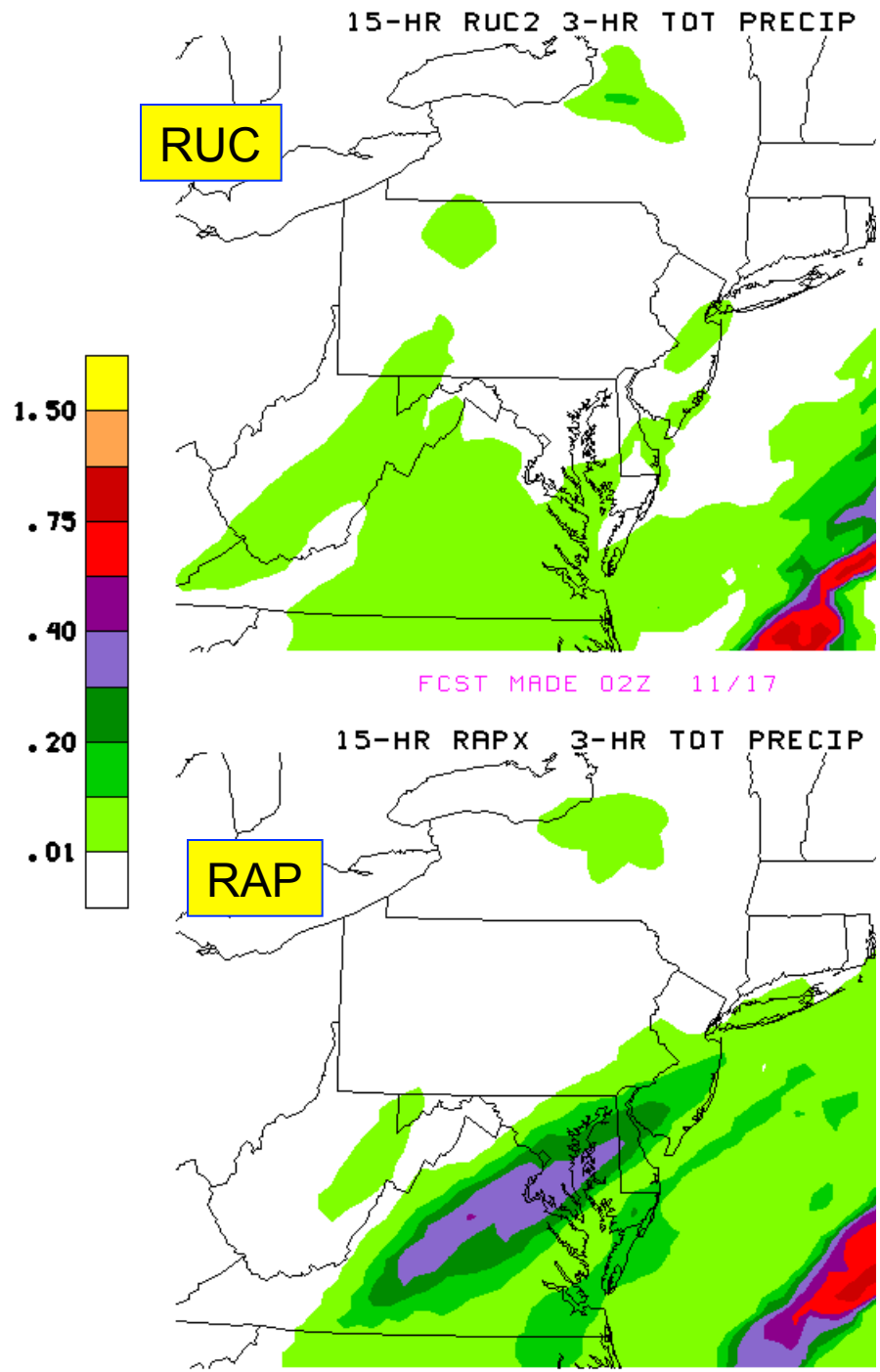

528
RUC

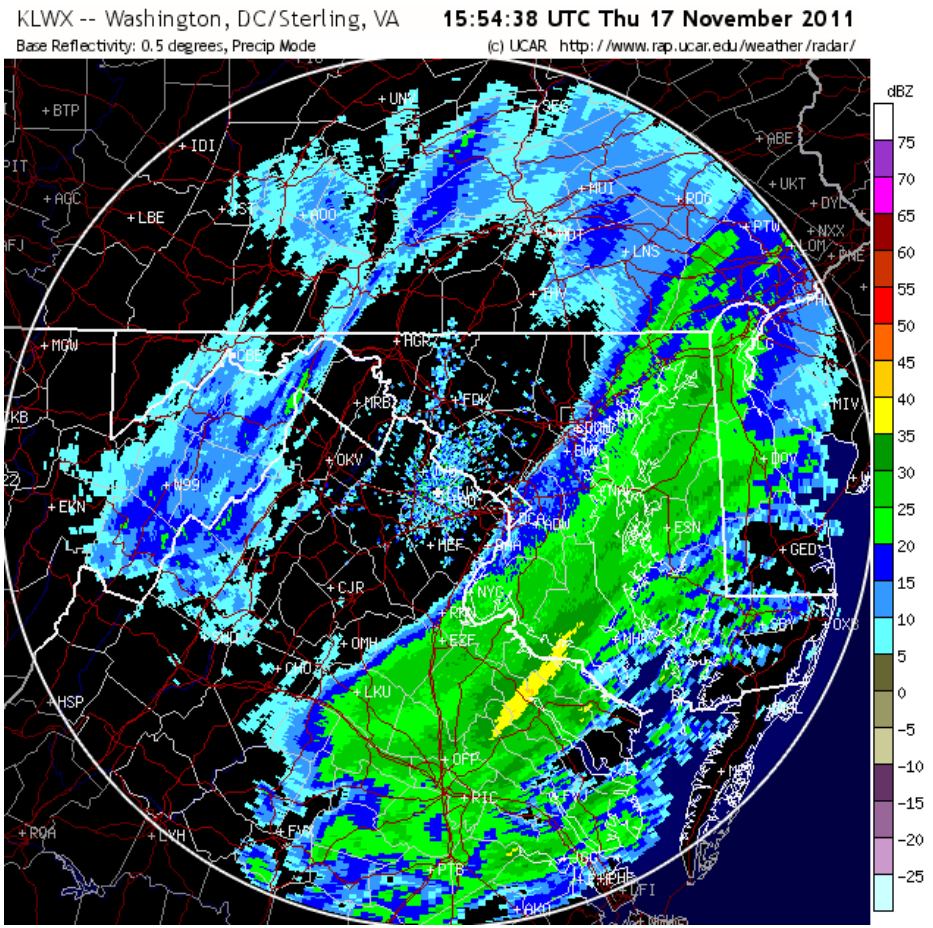

15-HR RUC2 3-HR TOT PRECIP
RUC
1.50
.75
.40
.20
.01
FCST MADE 02Z 11/17


09-HR RAPX FCST 500 HT/VORT
510
528
546
564
582
RAP


528
RAP

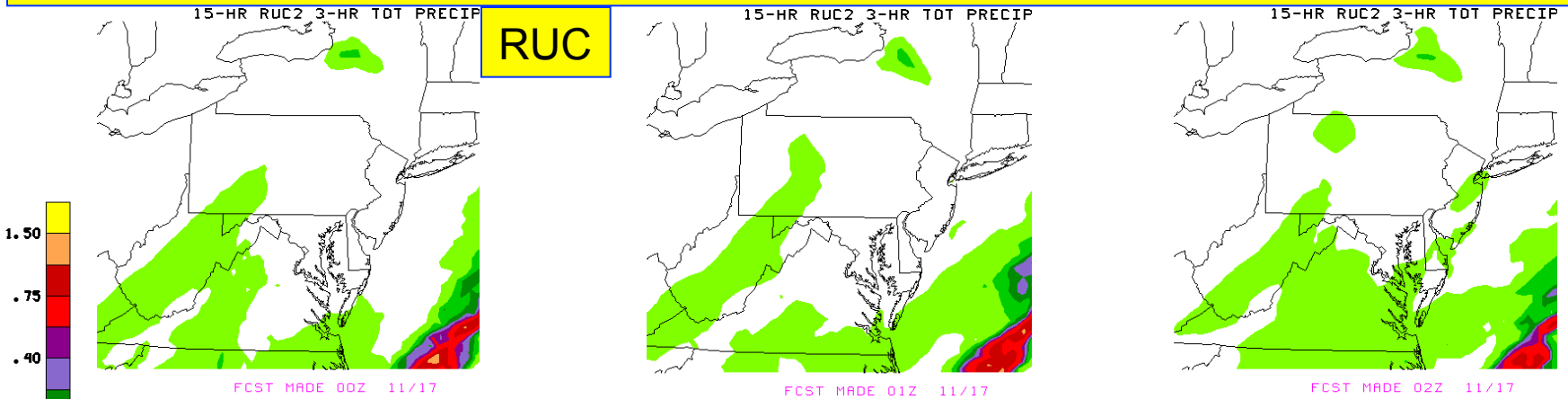

15-HR RAPX 3-HR TOT PRECIP
RAP


15-HR RUC2 3-HR TOT PRECIP
RUC
1.50
.75
.40
.20
.01
FCST MADE 02Z 11/17
15-HR RAPX 3-HR TOT PRECIP
RAP

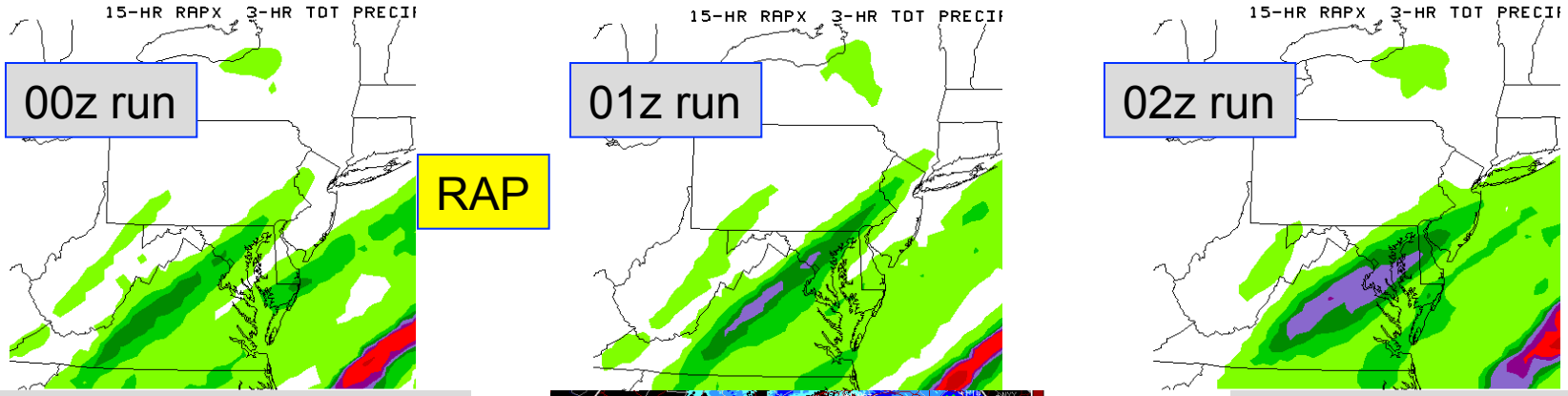

KLWX -- Washington, DC/Sterling, VA
15:54:38 UTC Thu 17 November 2011
Base Reflectivity: 0.5 degrees, Precip Mode
(c) UCAR http://www.rap.ucar.edu/weather/radar/
dBZ
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25

How a sequence of hourly RAP runs can help piece together a forecast issue:

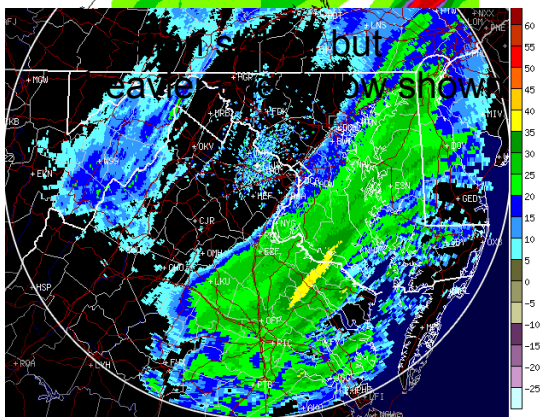
RUC



RAP

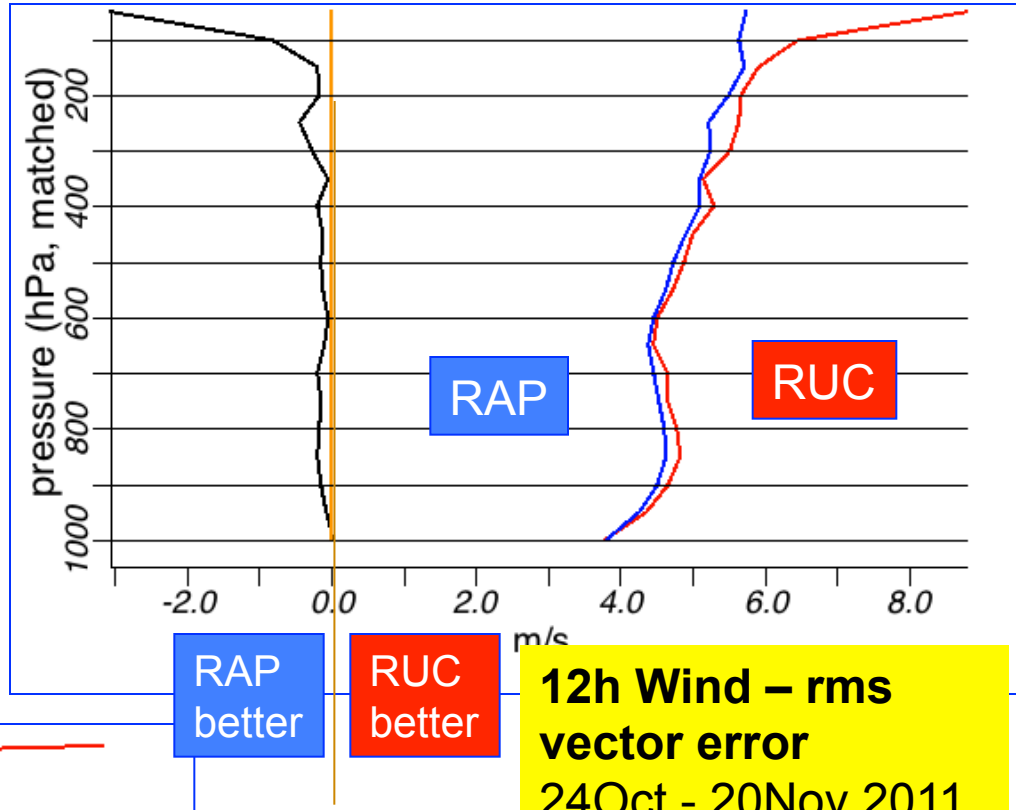


Location off but initial concept of event

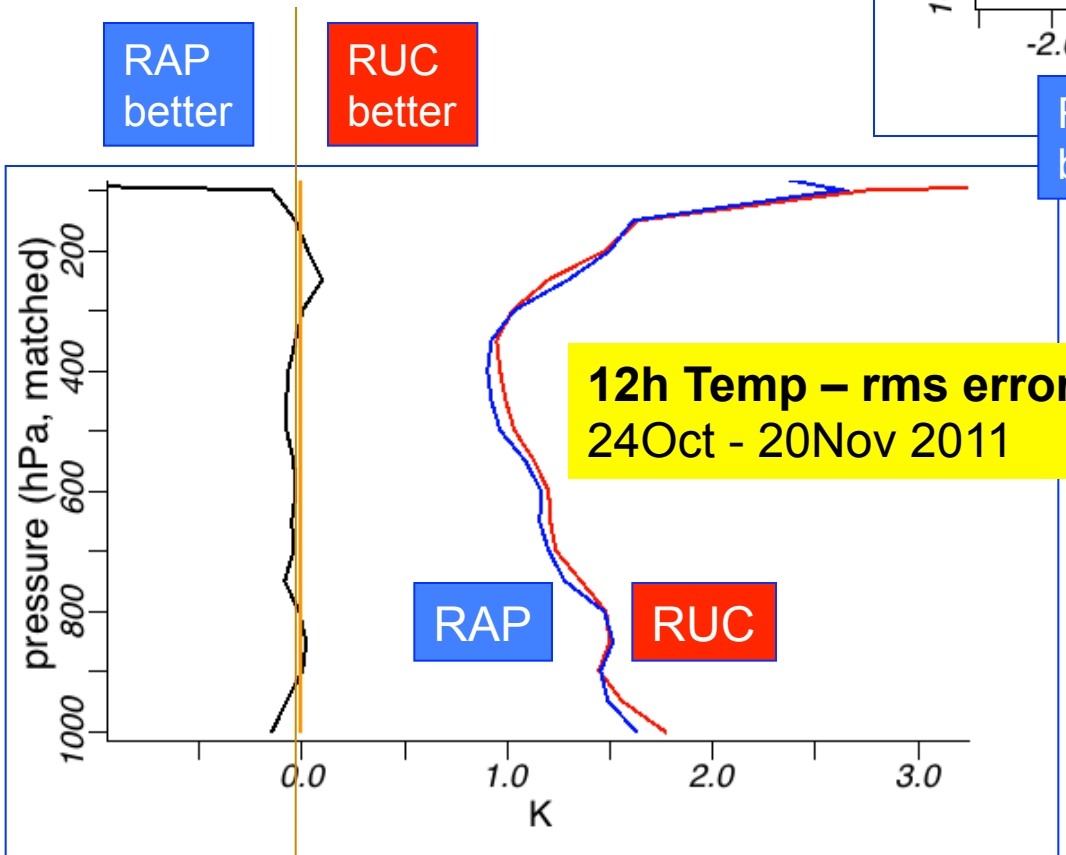


By 02z, starts to nail down location

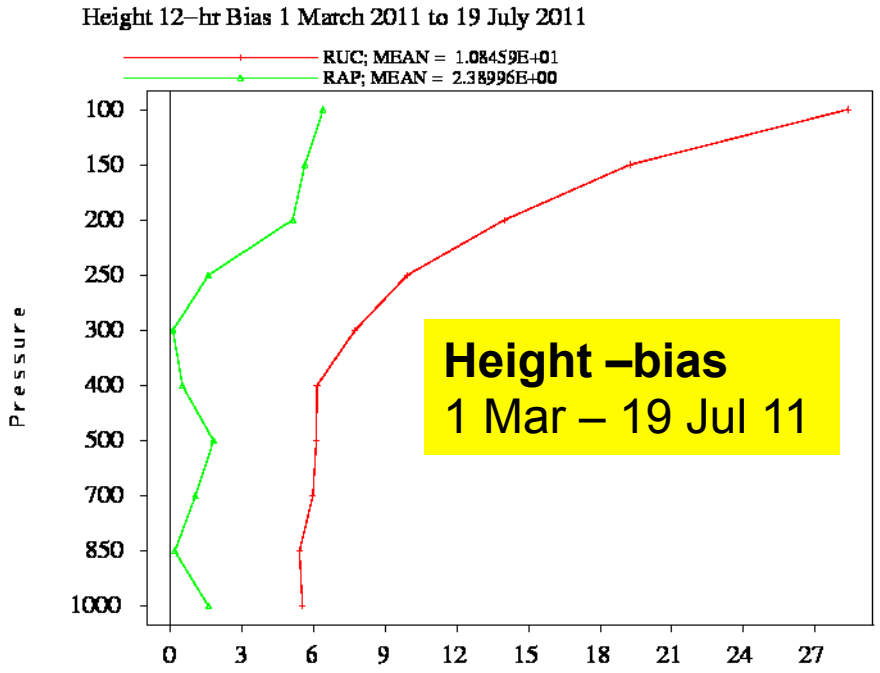
Raob verification: RUC-NCEP vs. RAP-NCEP(EMC)

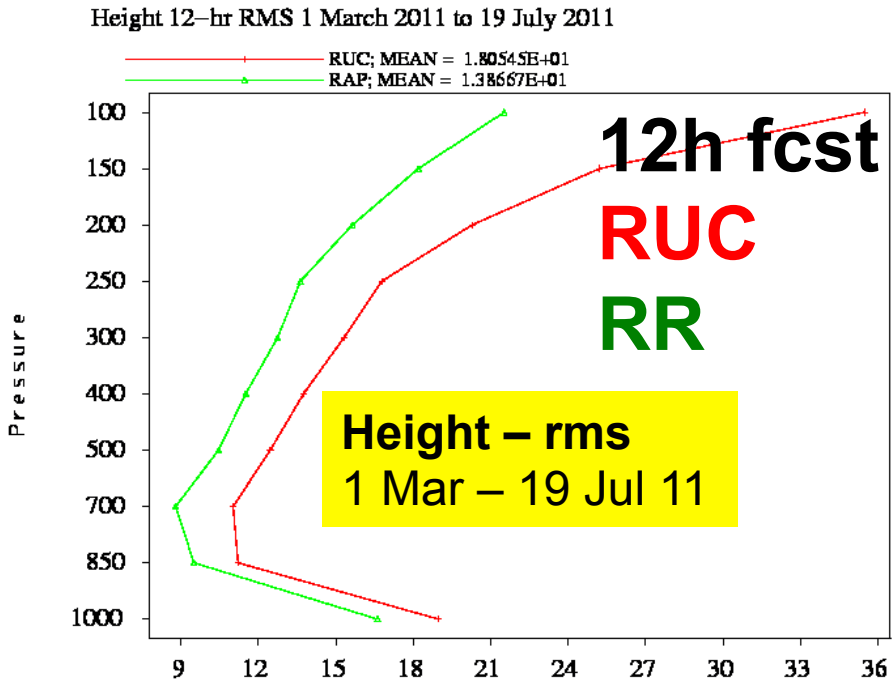


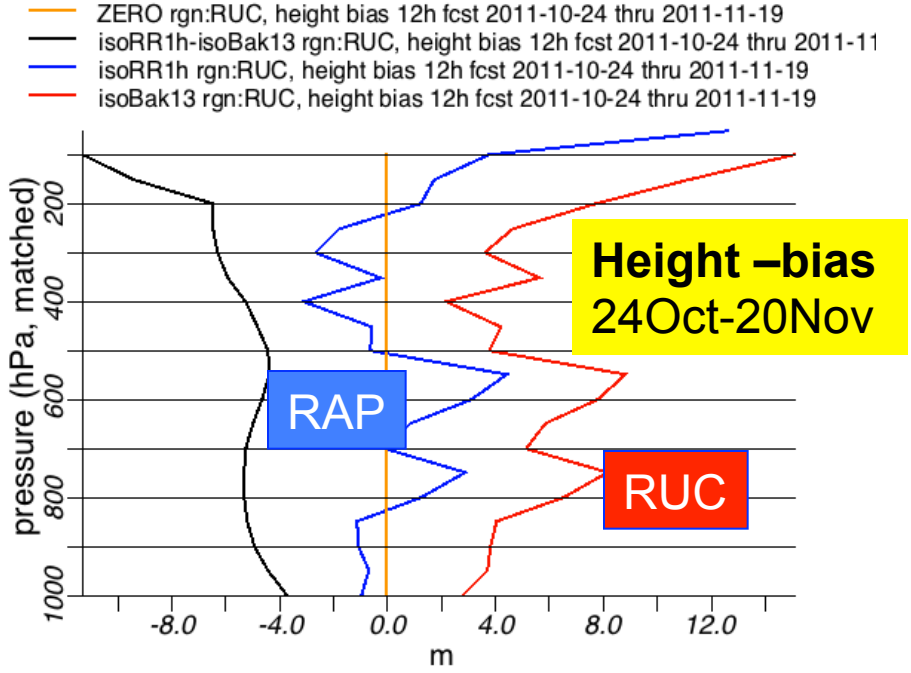
12h Wind – rms vector error
24Oct - 20Nov 2011

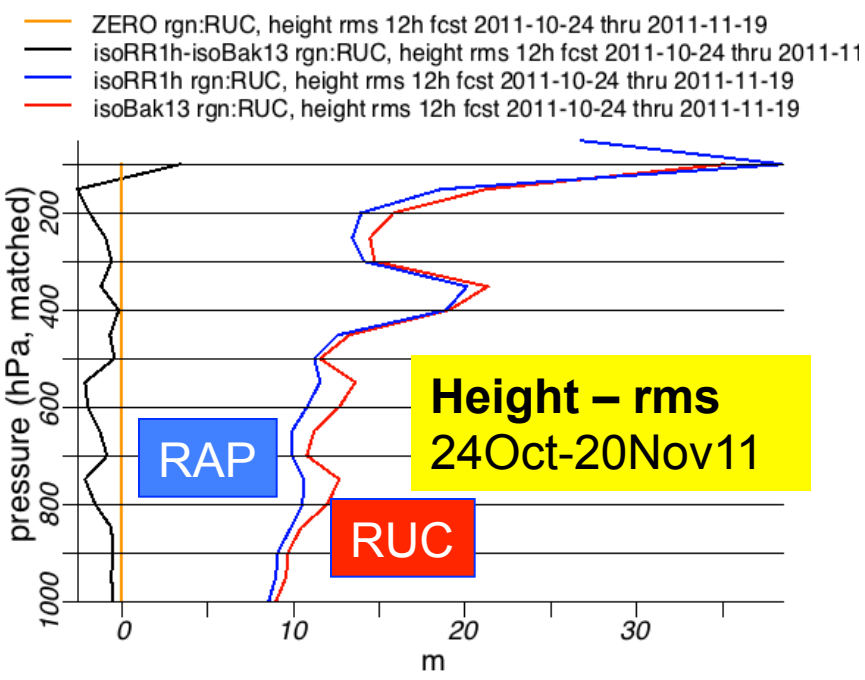


12h Temp – rms error
24Oct - 20Nov 2011


Height 12–hr Bias 1 March 2011 to 19 July 2011
RUC; MEAN = 1.08459E+01
RAP; MEAN = 2.38996E+00
Pressure
100
150
200
250
300
400
500
700
850
1000
0
3
6
9
12
15
18
21
24
27
Height –bias
1 Mar – 19 Jul 11


Height 12–hr RMS 1 March 2011 to 19 July 2011
RUC; MEAN = 1.80545E+01
RAP; MEAN = 1.38667E+01
Pressure
100
150
200
250
300
400
500
700
850
1000
9
12
15
18
21
24
27
30
33
36
12h fcst
RUC
RR
Height – rms
1 Mar – 19 Jul 11

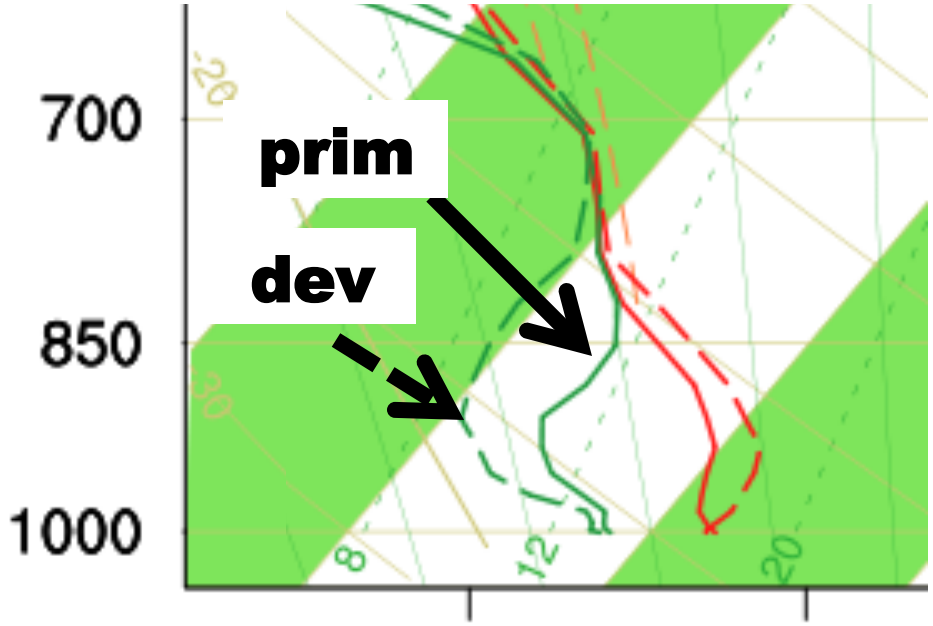

ZERO rgn:RUC, height bias 12h fcst 2011-10-24 thru 2011-11-19
isoRR1h-isoBak13 rgn:RUC, height bias 12h fcst 2011-10-24 thru 2011-11
isoRR1h rgn:RUC, height bias 12h fcst 2011-10-24 thru 2011-11-19
isoBak13 rgn:RUC, height bias 12h fcst 2011-10-24 thru 2011-11-19
pressure (hPa, matched)
200
400
600
800
1000
-8.0
-4.0
0.0
4.0
8.0
12.0
m
RAP
RUC
Height –bias
24Oct-20Nov


ZERO rgn:RUC, height rms 12h fcst 2011-10-24 thru 2011-11-19
isoRR1h-isoBak13 rgn:RUC, height rms 12h fcst 2011-10-24 thru 2011-11
isoRR1h rgn:RUC, height rms 12h fcst 2011-10-24 thru 2011-11-19
isoBak13 rgn:RUC, height rms 12h fcst 2011-10-24 thru 2011-11-19
pressure (hPa, matched)
200
400
600
800
1000
0
10
20
30
m
RAP
RUC
Height – rms
24Oct-20Nov11

Later in 2012, Rapid Refresh 2, changes already running in ESRL RR/HRRR

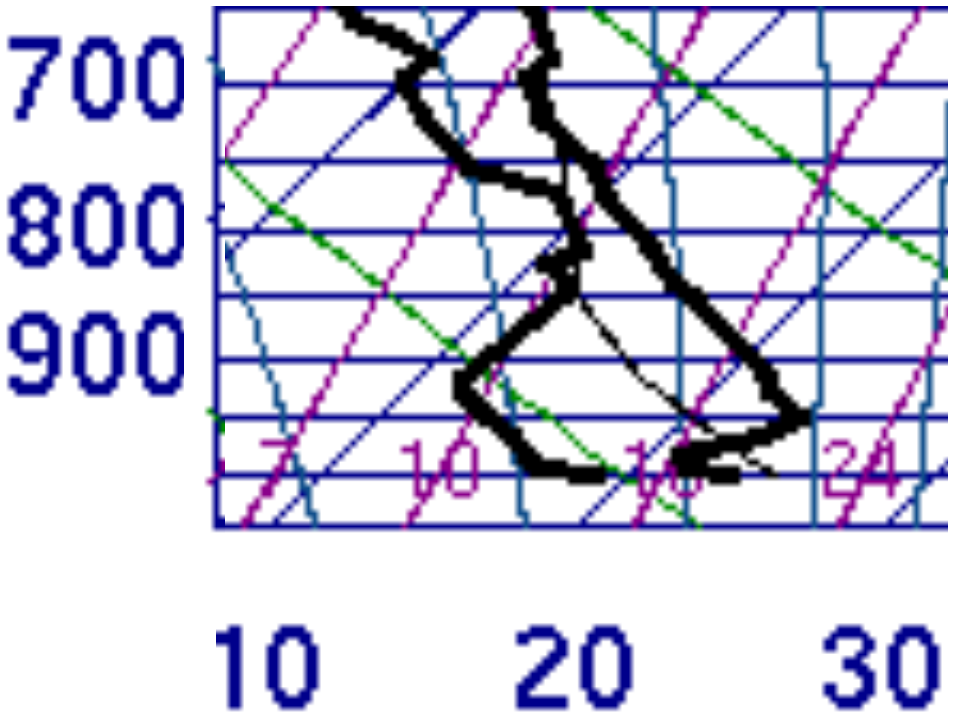
Rapid Refresh prim (——) vs. dev (- - - -)
RR-dev has PBL-based pseudo-observations

Residual mixed layer better depicted in RR-dev (w/ PBL pseudo-obs)



23z 6 July 2011
RR sounding

Observed
00z 7 July 2011
Albany, NY sounding



Also in ESRL RR/HRRR - Soil moisture/temperature adjustment

Rapid Refresh prim (——) vs. dev (——) 24 Sept-15 Nov difference - RR-dev has soil adjustment starting 24 Sept

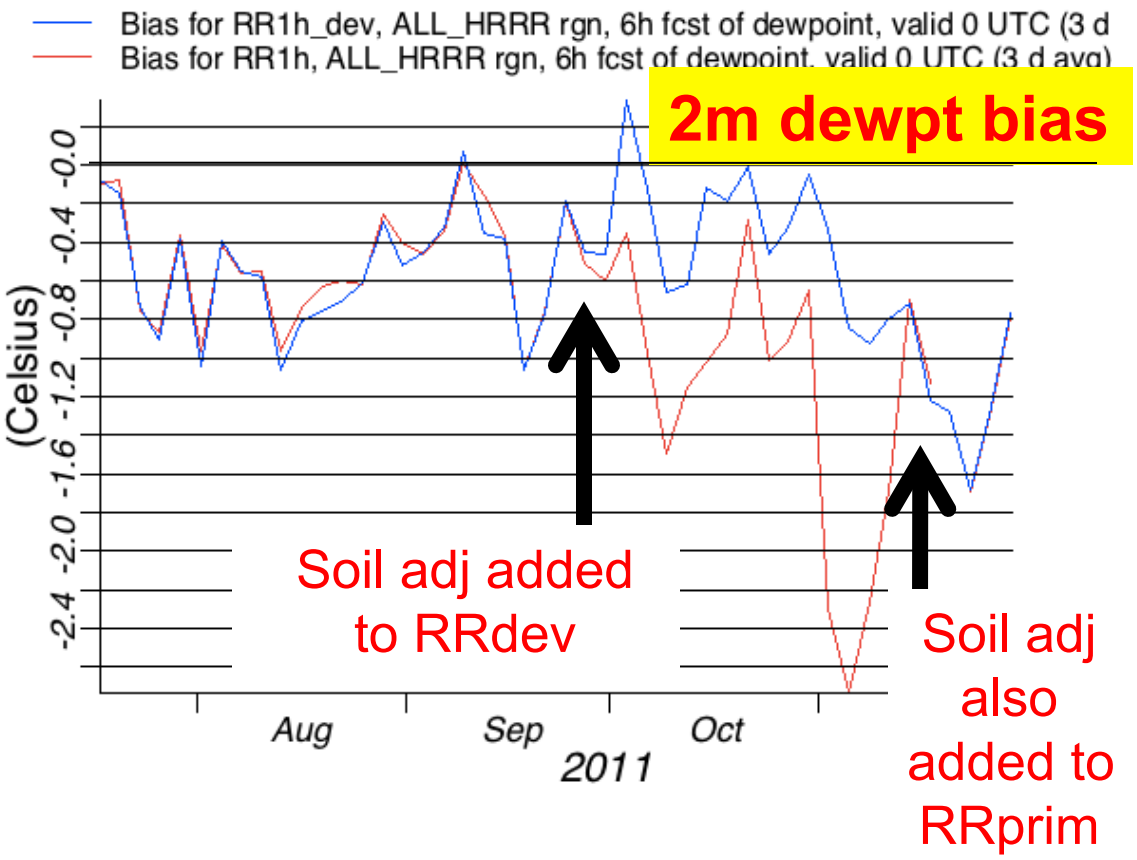
Soil adjustment q'_{soil}

- applied if

- ***T'(k=1) and q'(k=1) are of opposite sign***
- ***Daytime***
- ***No clouds***
- ***Proportional to q'(k=1)***

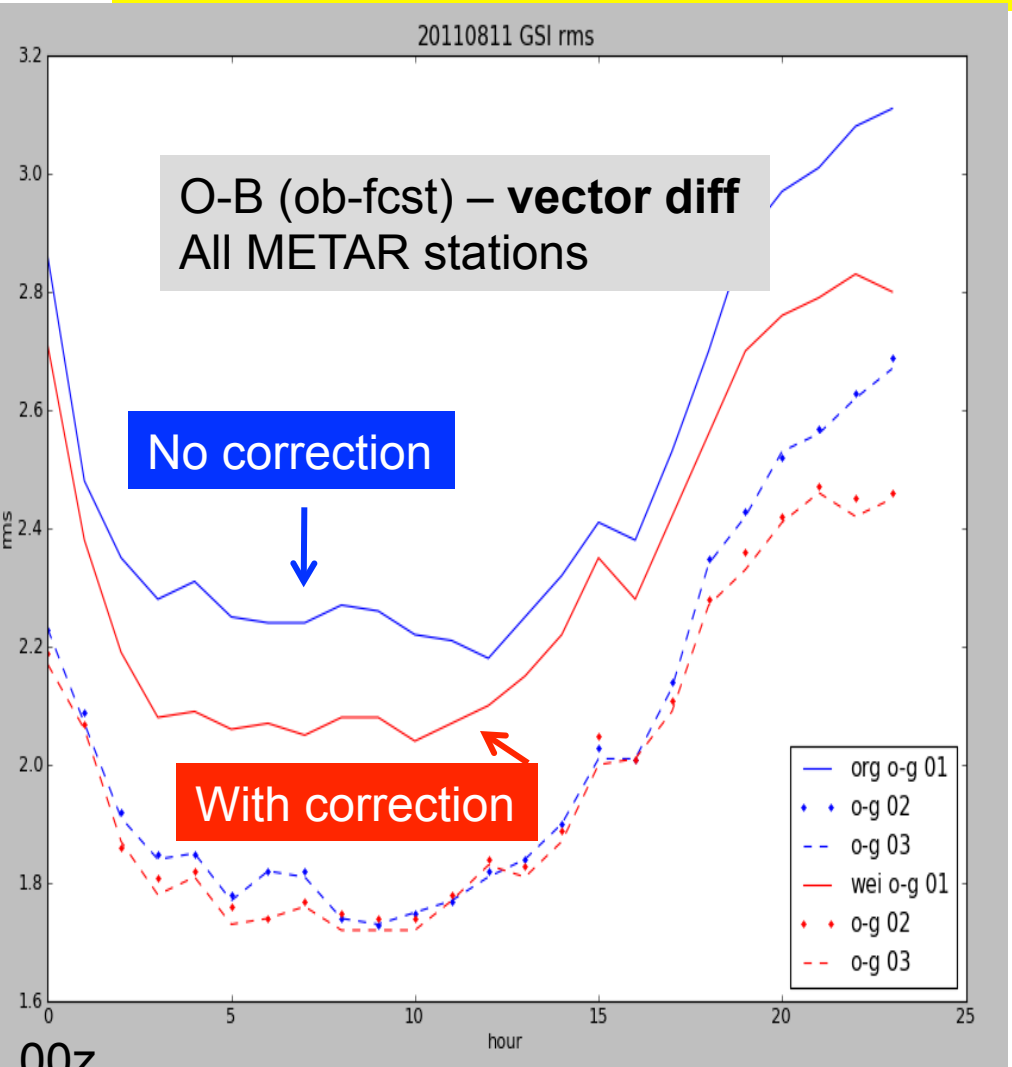
Assumption – Bowen ratio error from soil moisture error

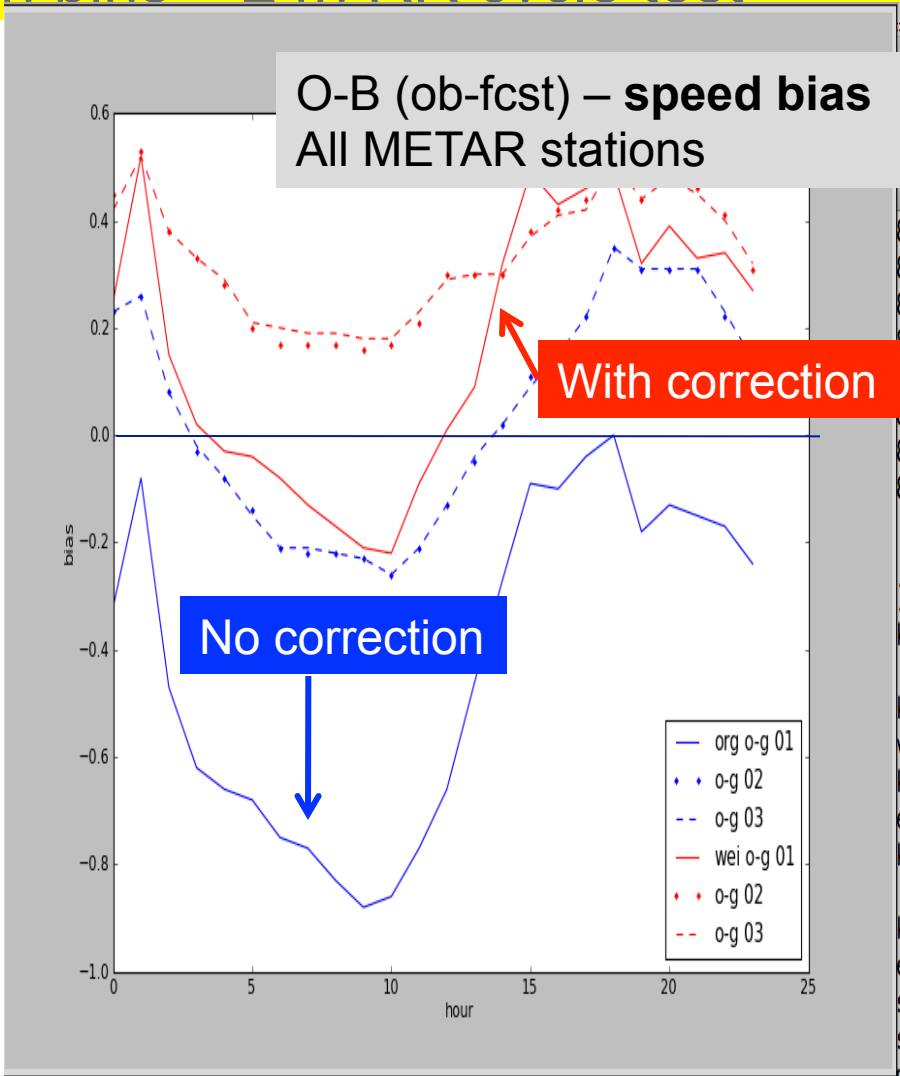
- **Applied at top 2 levels in RUC LSM**
- **Used in RUC since 2005**



Coming this winter to ESRL RR/HRRR - surface ob wind correction

Historical database for each surface station, ob-fcst difference for 9 different wind direction bins – 24h RR cycle test





RAP upgrades for RAP2 proposed for late 2012 (already successfully tested in RAP @ ESRL)

- Moisture PBL-based pseudo-observations
- Soil adjustment from near-sfc temp/moisture analysis increment

(Last 2 important for convective environment, both in RUC but not yet in NCEP RAP)

- MODIS land use, Assimilation of radial wind, lightning, mesonet data

<u>Starting now in testing in ESRL RAP</u>

- WRFv3.3.1, improved vertical advection, upper boundary condition
- GOES radiances

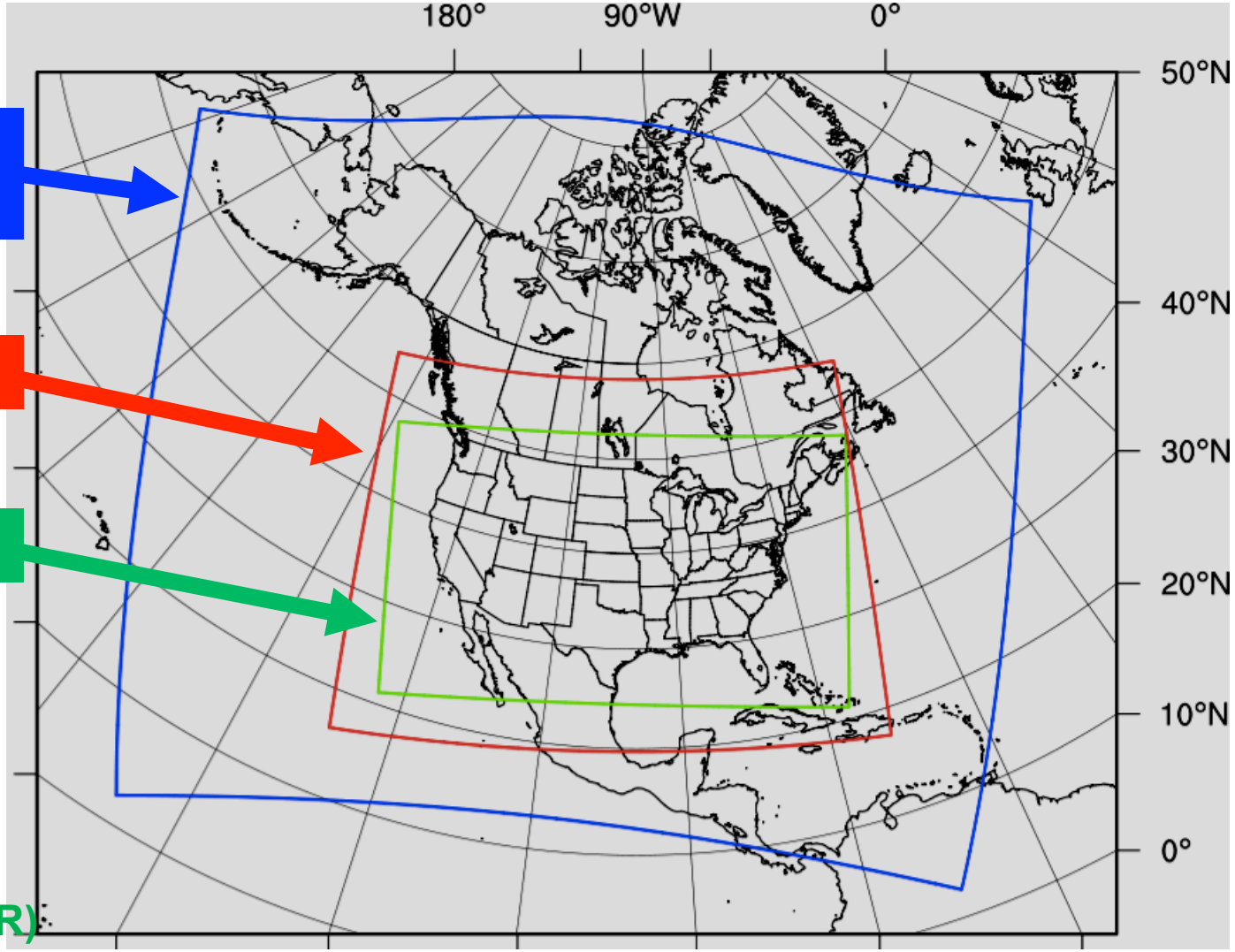
Hourly Updated NOAA NWP Models

Rapid Refresh (RR) replaces RUC at NCEP - WRF, GSI with RUC-based enhancements

13km Rapid Refresh

13km RUC

3km HRRR



RUC – current oper model, new 18h fcst every hour

High-Resolution Rapid Refresh (HRRR)

Experimental 3km nest inside RUC or RR, new 15-h fcst every hour

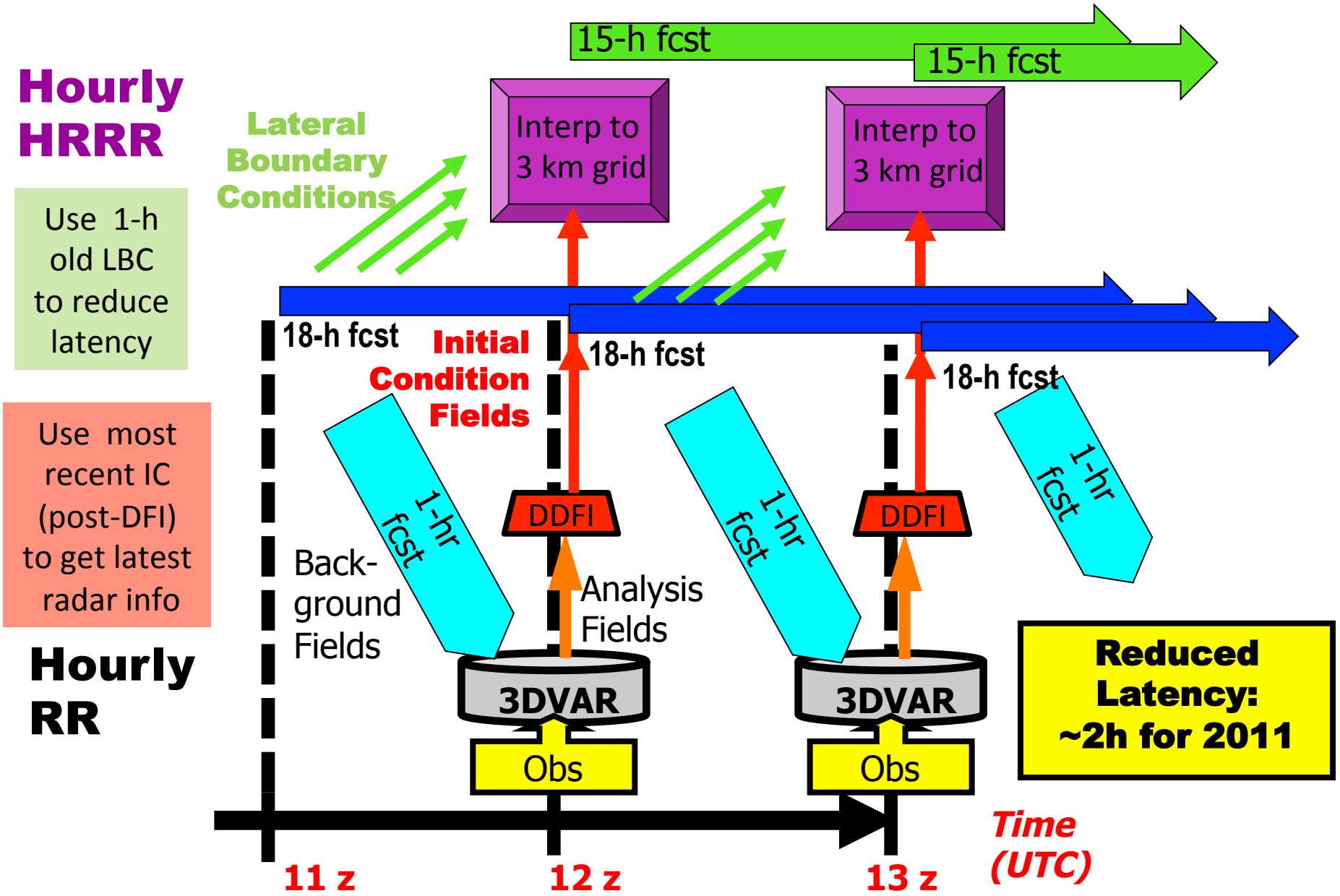
RR and HRRR Model Descriptions

Model	Grid Spacing	Vertical Levels	Vertical Coordinate	Lowest Model Level	Boundary Conditions	Initialized
RR	13 km	50	Sigma	~8 m AGL	GFS	Hourly (cycled)
HRRR	3 km	50	Sigma	~8 m AGL	RR	Hourly **(no-cycle)**

Model	Version	Assimilation	Radar DFI	Radiation	Microphysics	Cum Param	PBL	LSM
RR	WRF-ARW v3.2+	**GSI-3DVAR**	**Yes**	RRTM/ Goddard	Thompson	**G3 + Shallow**	MYJ	RUC
HRRR	WRF-ARW v3.2+	**None: RR I.C.**	**No**	RRTM/ Goddard	Thompson	**None**	MYJ	RUC

April 14, 2011: HRRR parent assimilation / model system switched from RUC to rapid Refresh

Spring 2011 Hourly HRRR Initialization from RR



RR radar assimilation and HRRR

- Radar-DFI is cycled on13-km RR (parent) grid
- No cycling or radar DA on 3-km HRRR (child) grid

→ Storms must "spin-up" within each HRRR run

How effective is cycled "radar-DFI" procedure applied on mesoscale grid?

-- for mesoscale "parent" grid?

-- for storm-scale "child" grid?

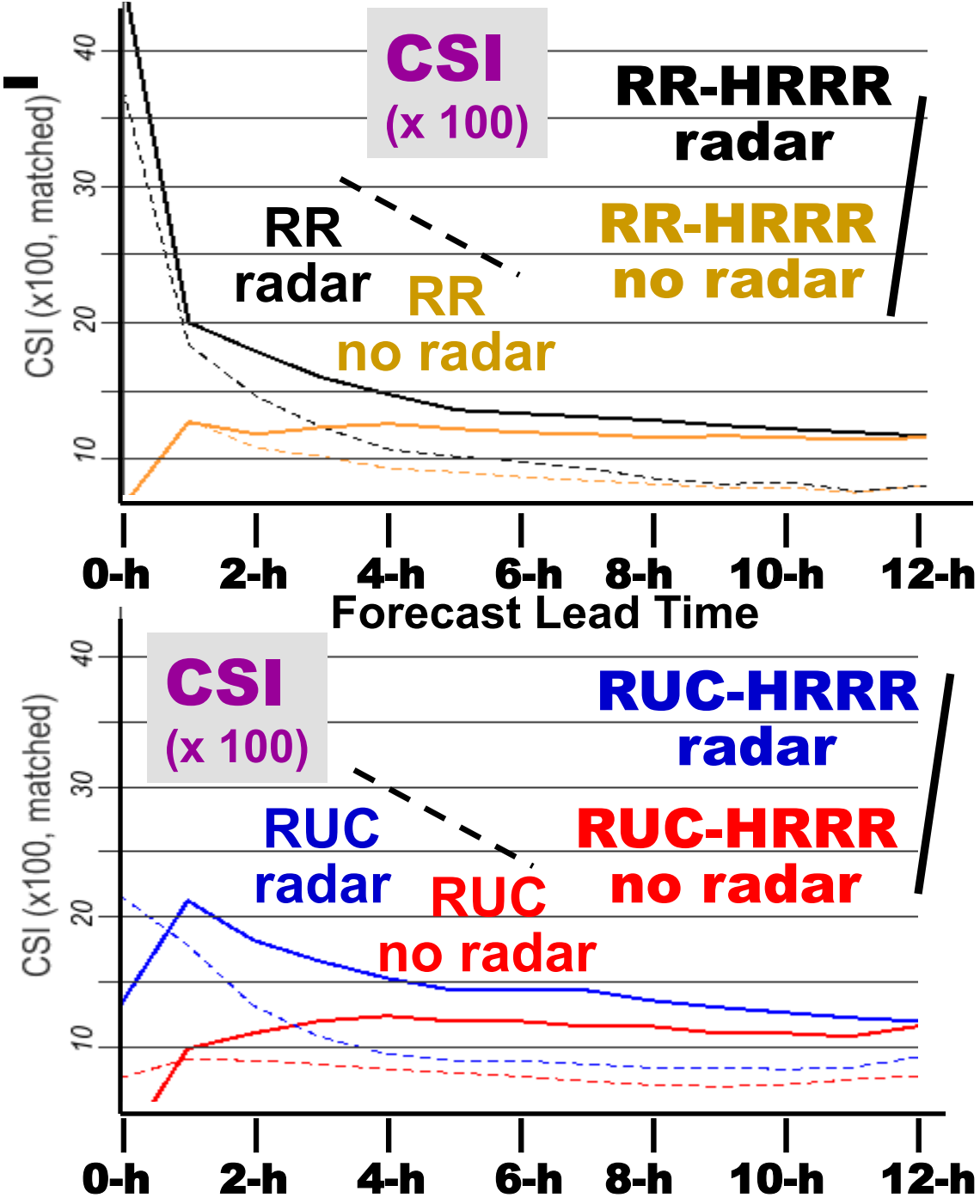
Reflectivity is assimilated, but used to modify velocity field

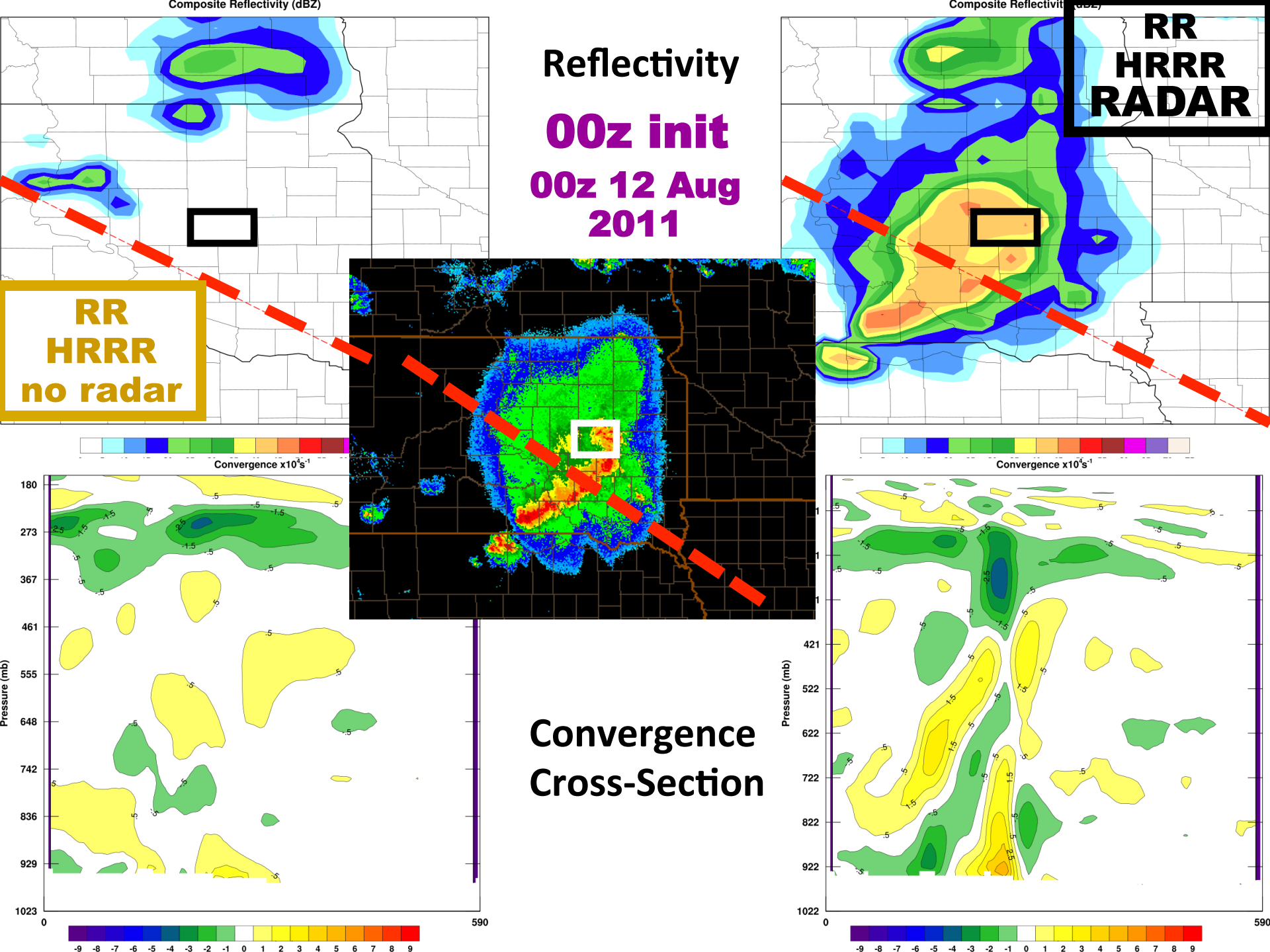
"parent" – – – –
vs. "child" ——
Reflectivity Verification

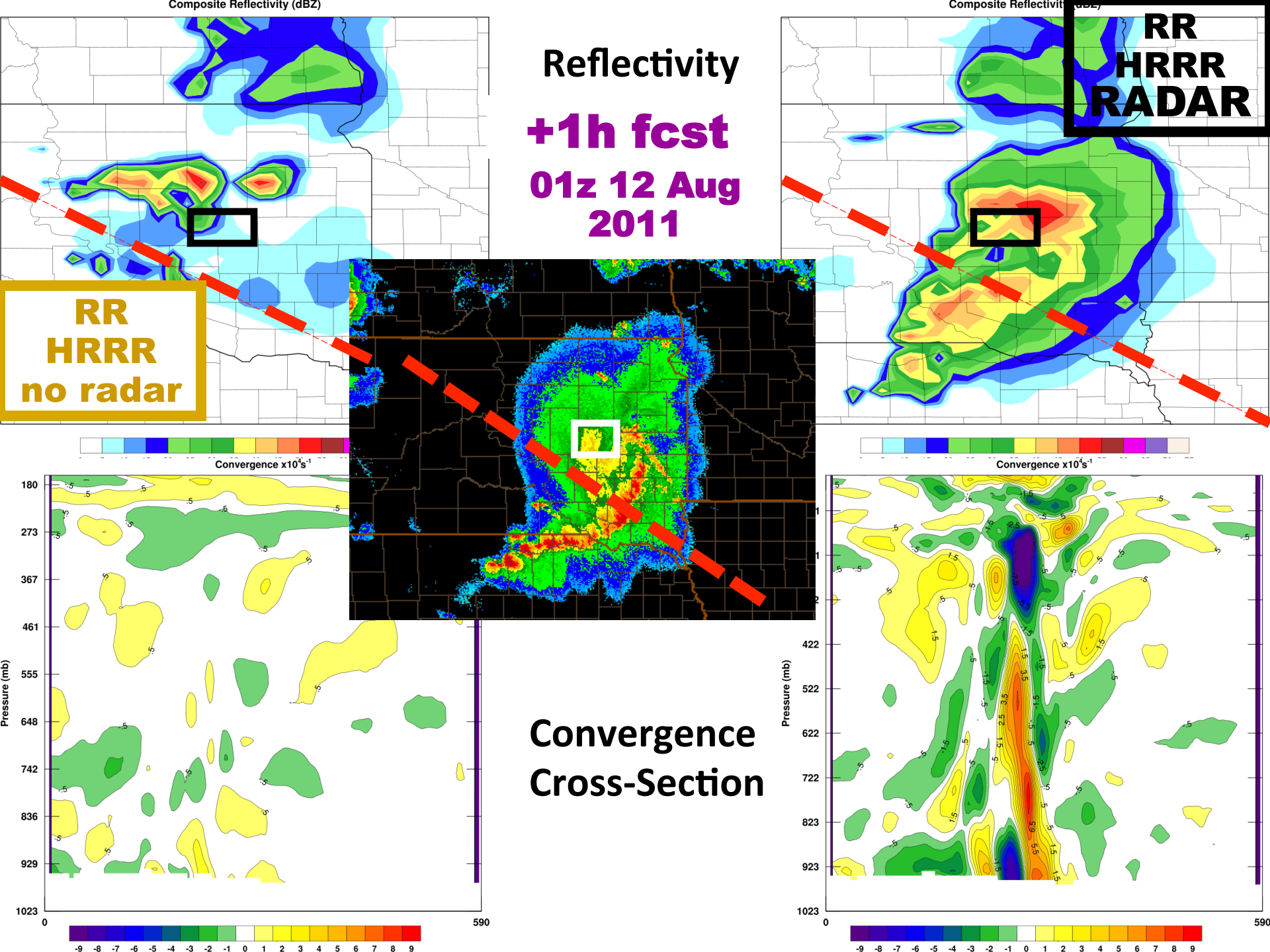
25 dBZ 13-km
Eastern US

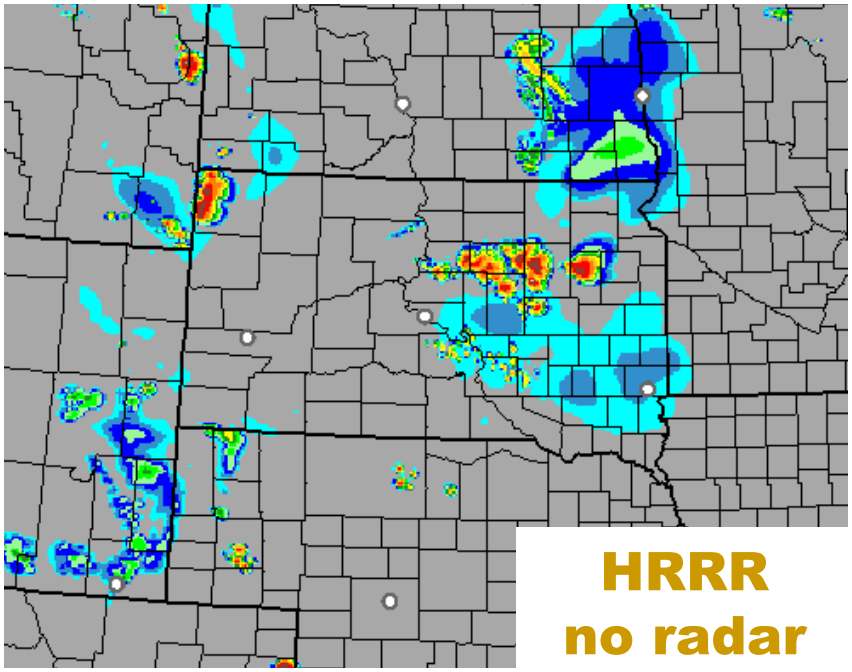
Matched Comparison
12,13,14,19 Aug. 2011
All init times

→3-km fcsts improve upon parent 13-km forecasts
→ radar assim adds skill at both 13-km and 3-km

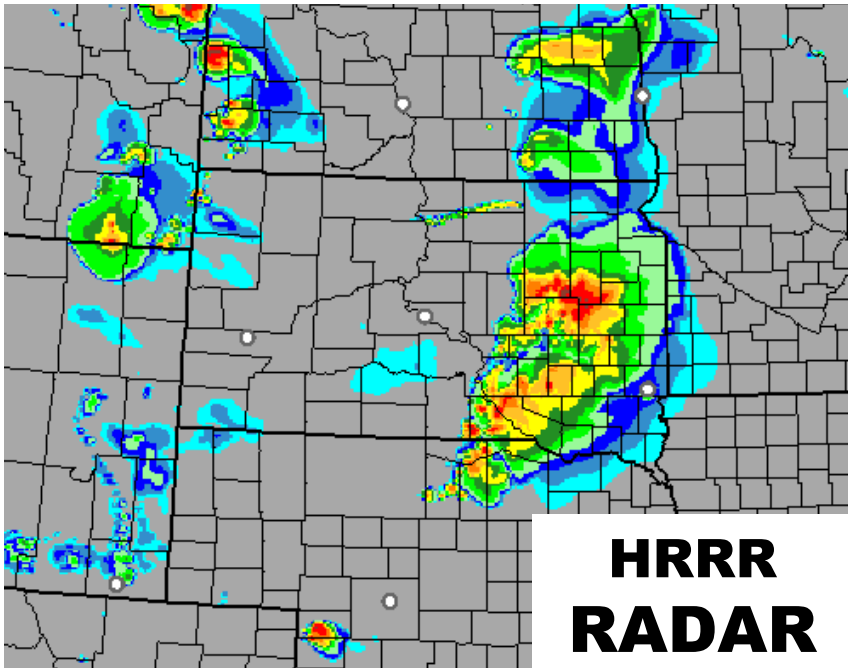



Composite Reflectivity (dBZ)
Reflectivity
00z init
00z 12 Aug 2011
RR
HRRR
RADAR
RR
HRRR
no radar
Convergence x10⁴s⁻¹
Pressure (mb)
180
273
367
461
555
648
742
836
929
1023
0
590
Convergence Cross-Section
421
522
622
722
822
922
1022


Composite Reflectivity (dBZ)
Reflectivity
+1h fcst
01z 12 Aug 2011
RR
HRRR
RADAR
RR
HRRR
no radar
Convergence x10^{4}s^{-1}
Pressure (mb)
180
273
367
461
555
648
742
836
929
1023
0
590
-9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9
Convergence
Cross-Section

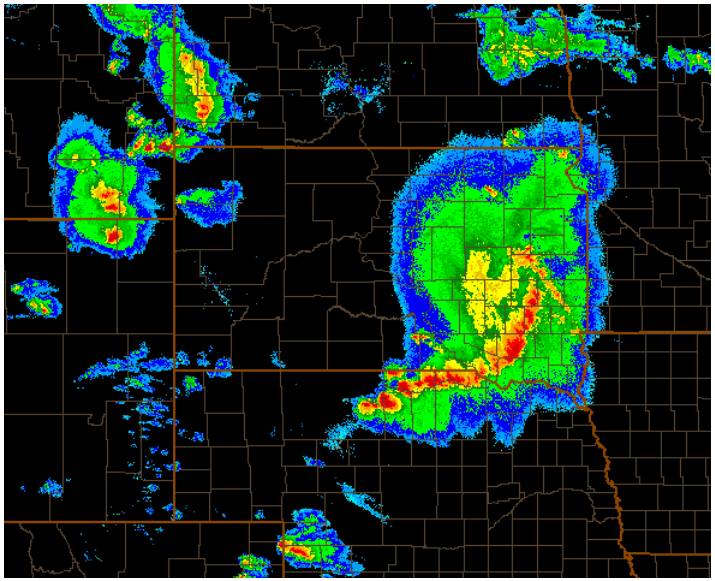


HRRR
no radar

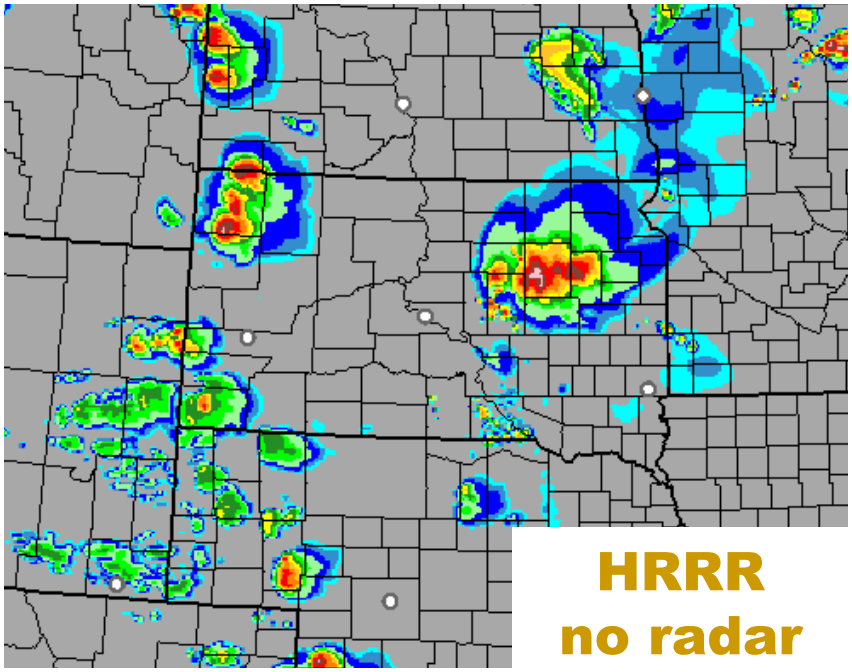


HRRR
RADAR

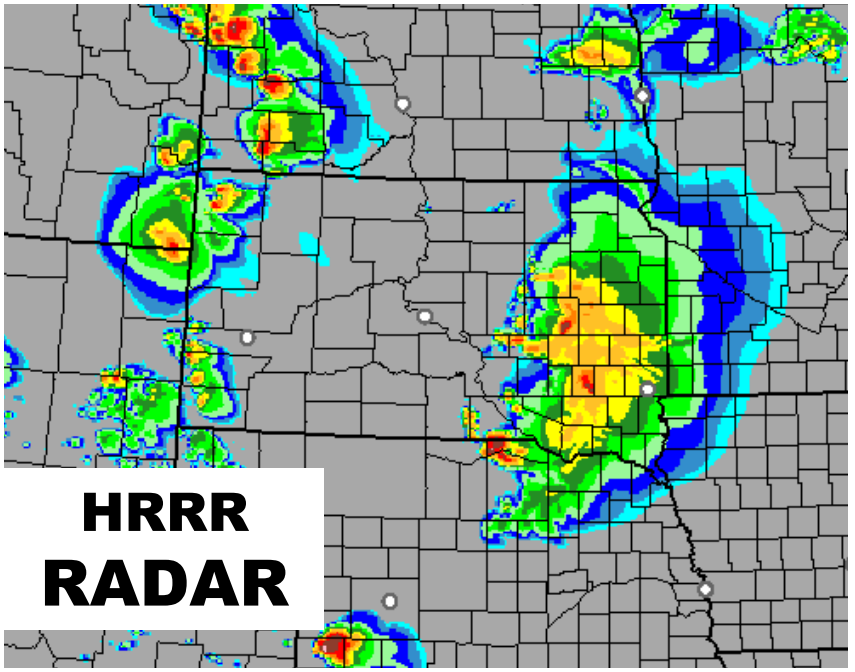
+1h fcsts



Valid:
01z 12 Aug
2011

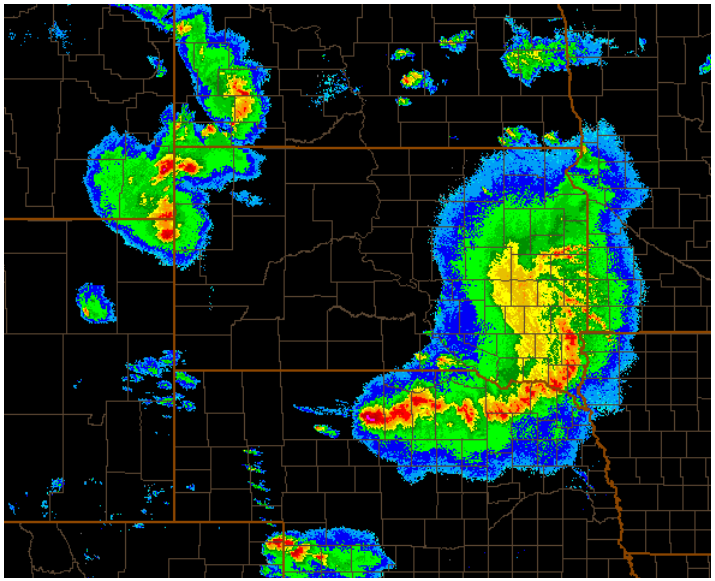


HRRR
no radar

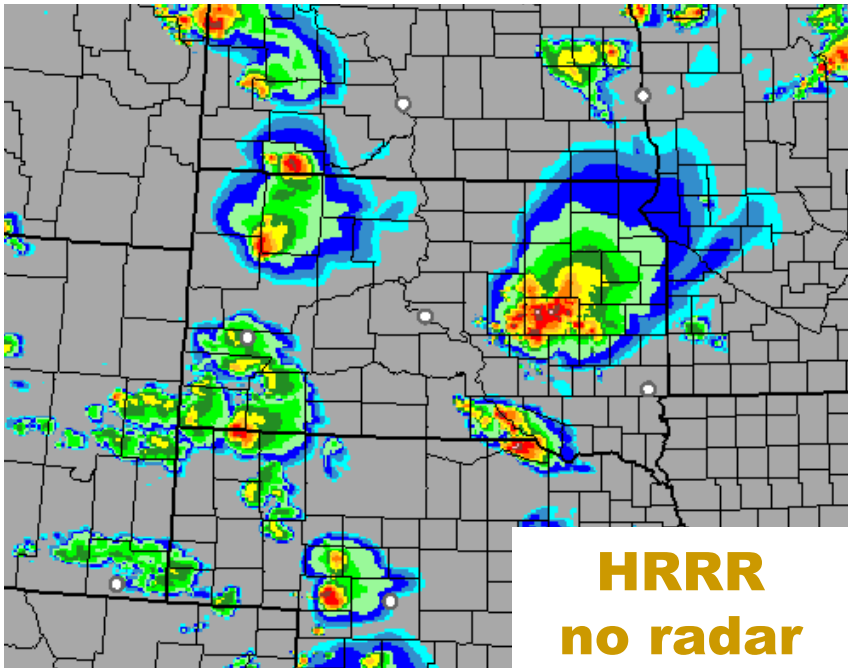


HRRR
RADAR

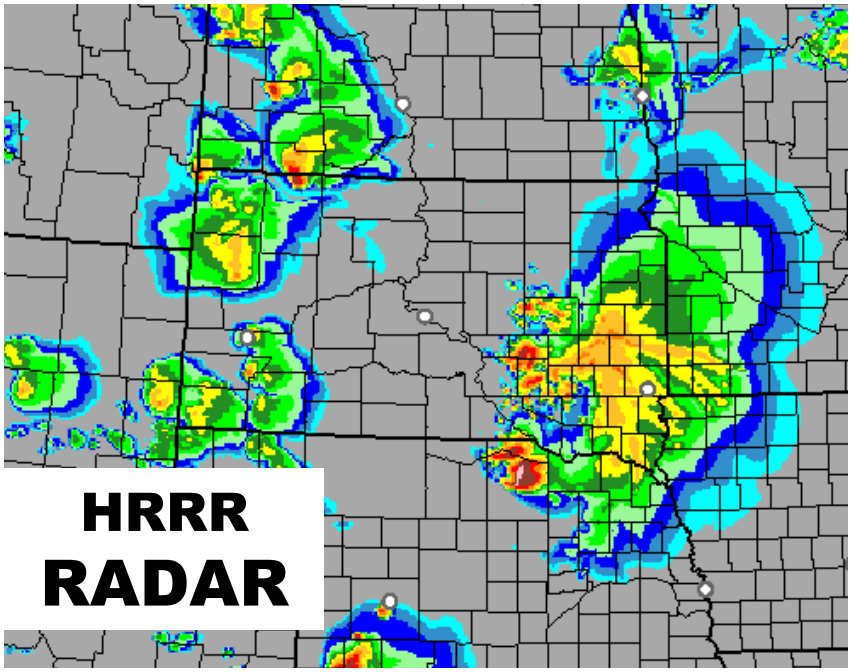
+2h fcsts



Valid:
02z 12 Aug
2011

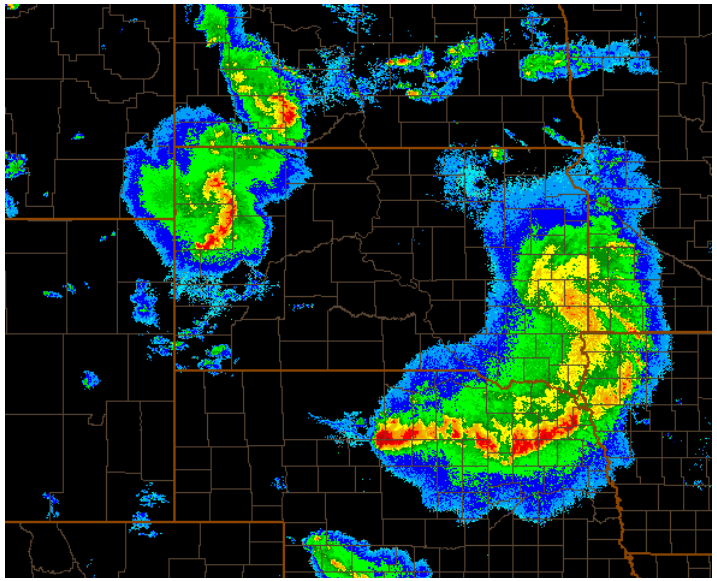


HRRR
no radar

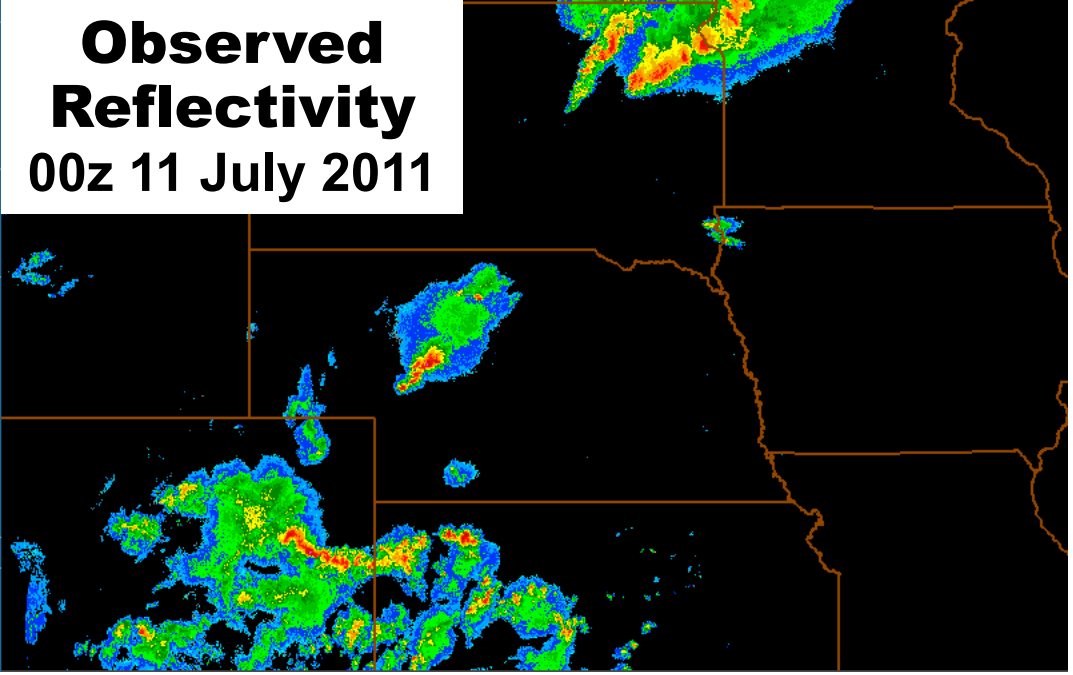


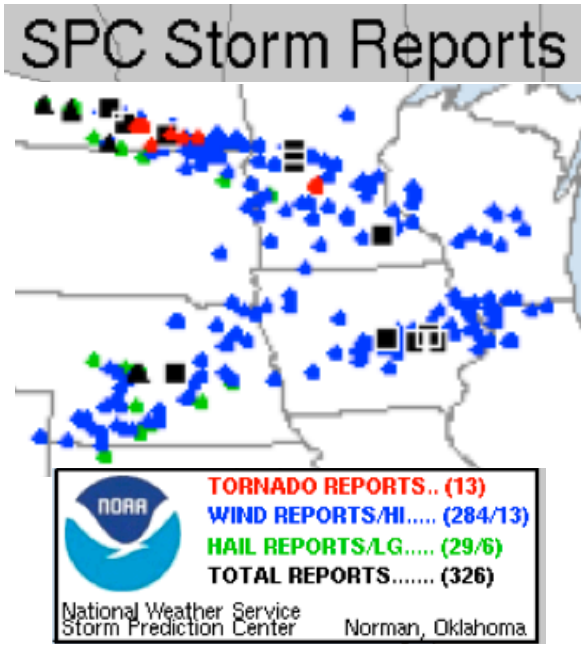
HRRR
RADAR

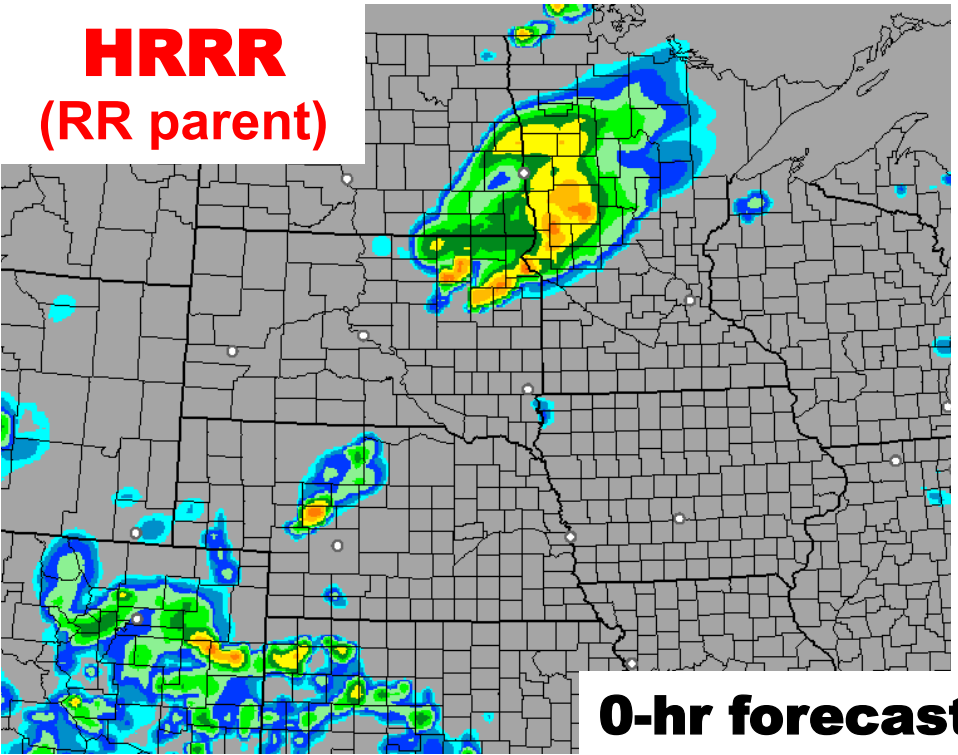
+3h fcsts

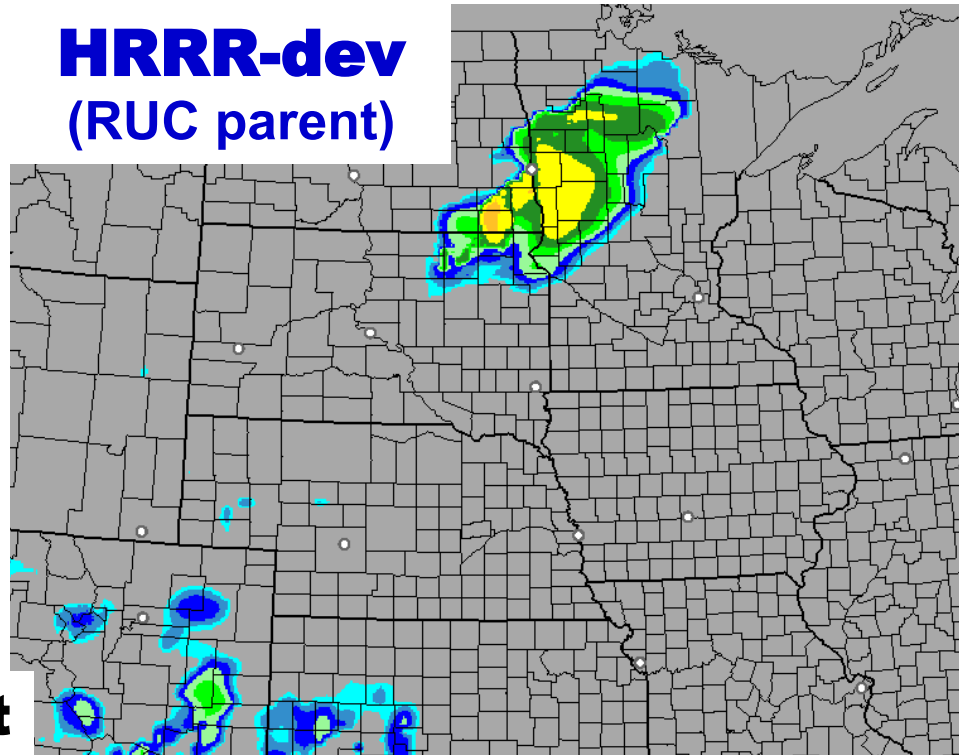


Valid:
03z 12 Aug
2011

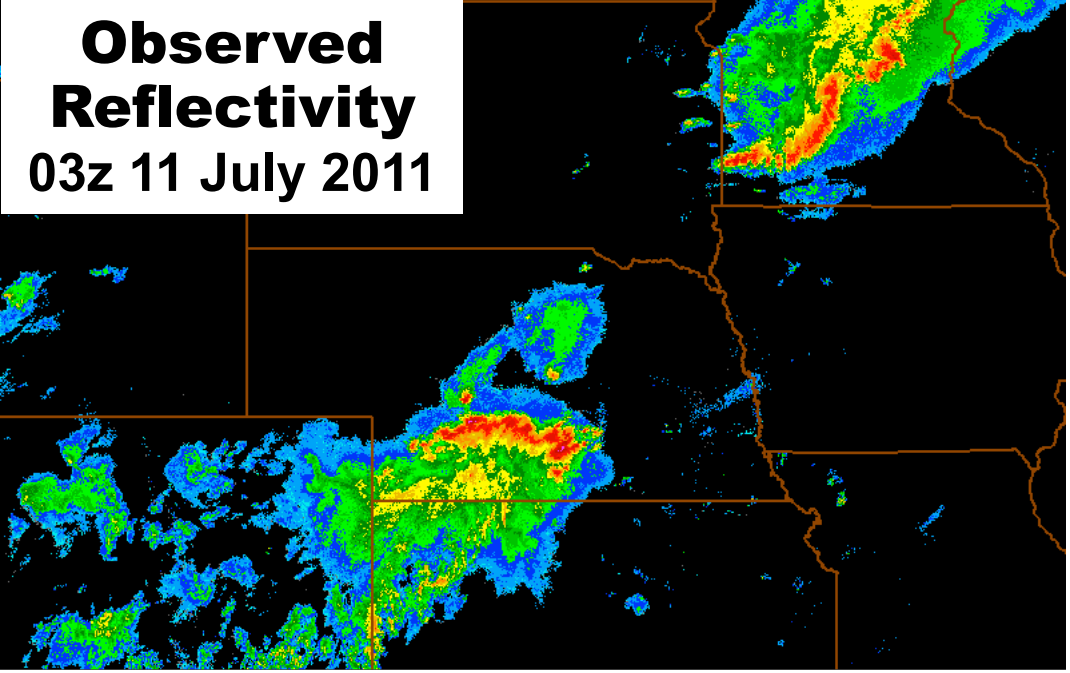


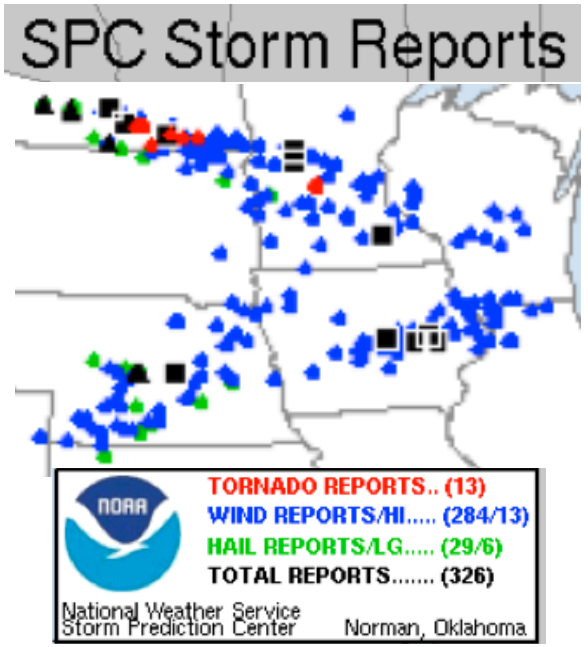


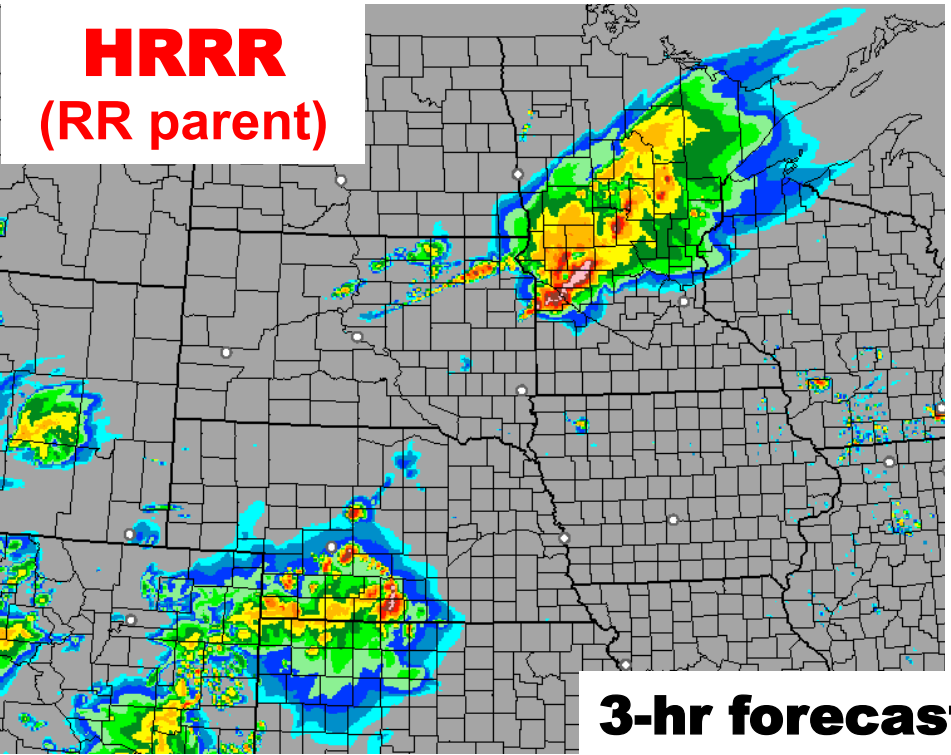


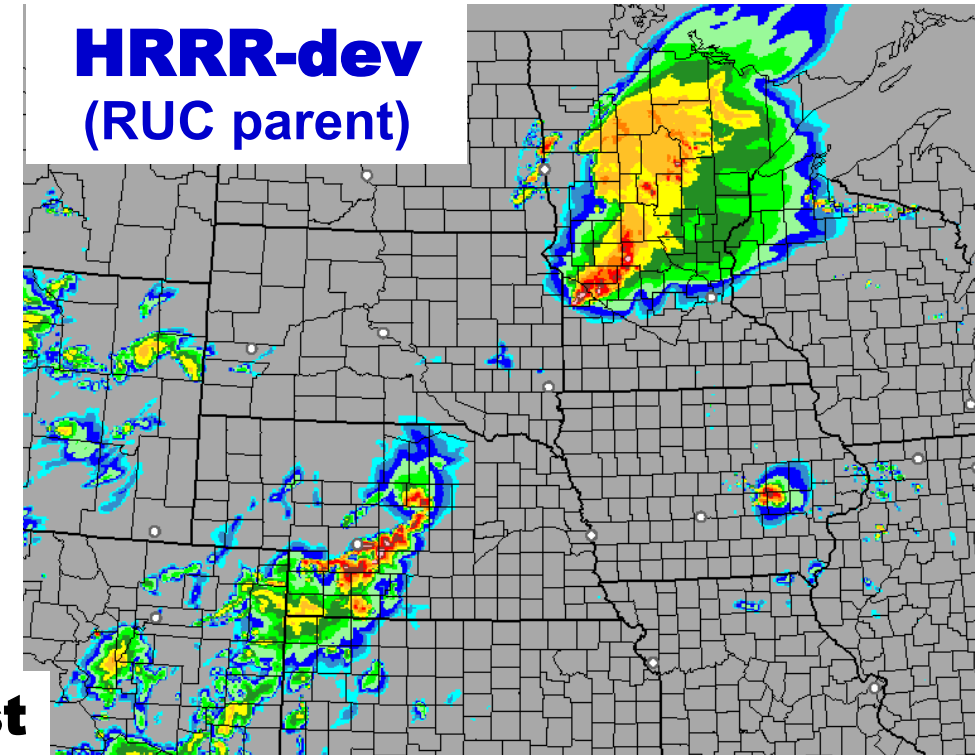


0-hr forecast

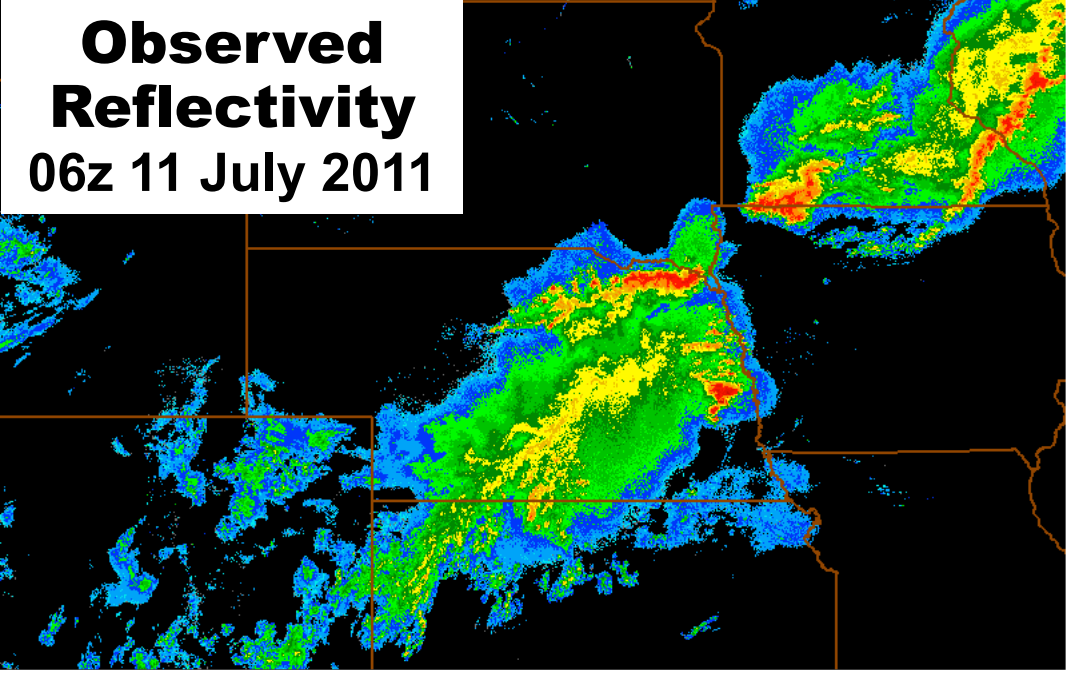


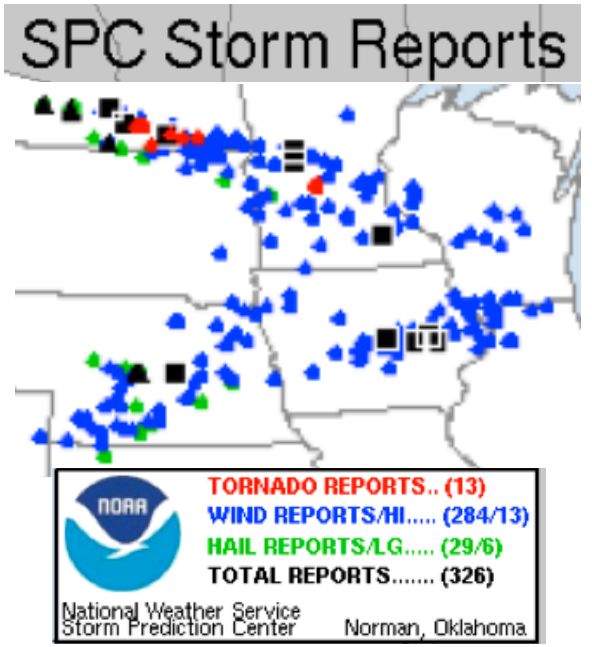


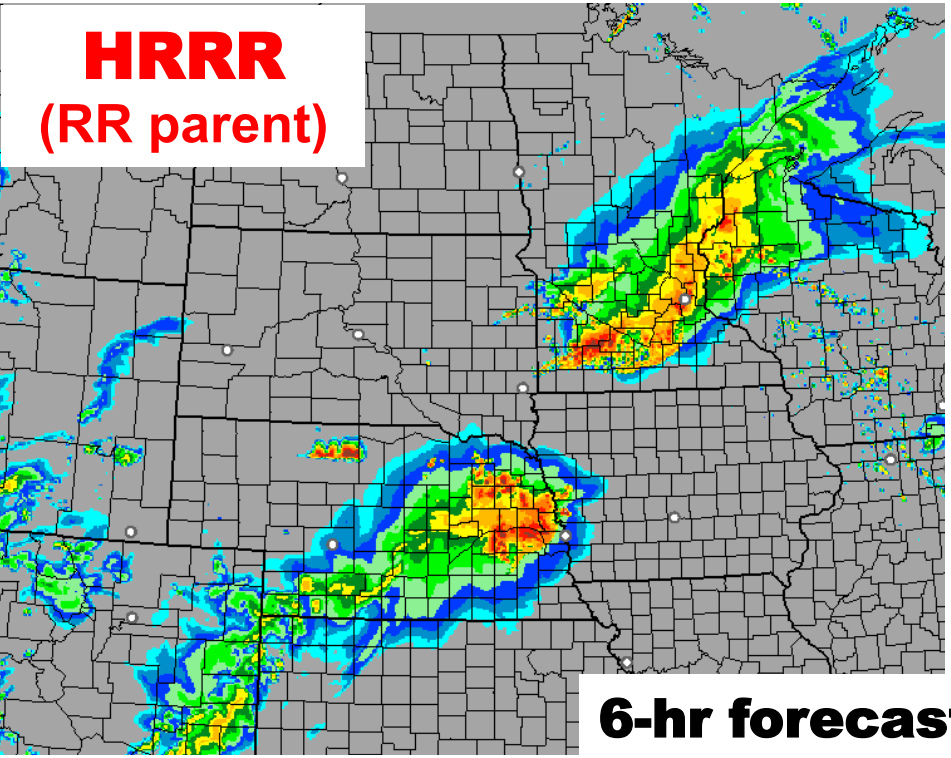


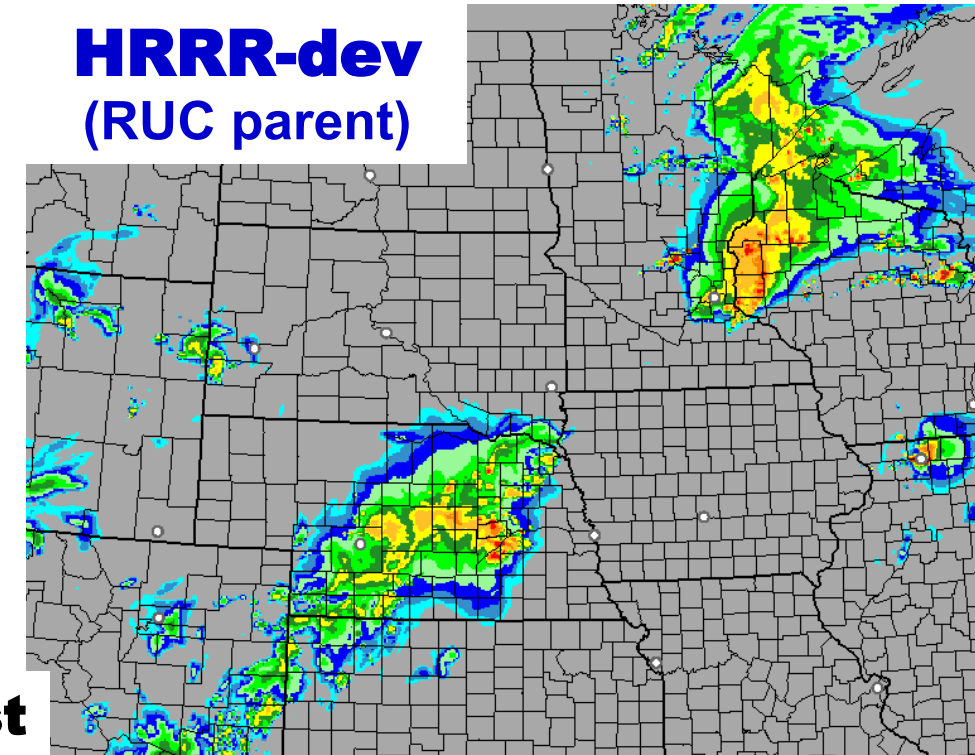


3-hr forecast

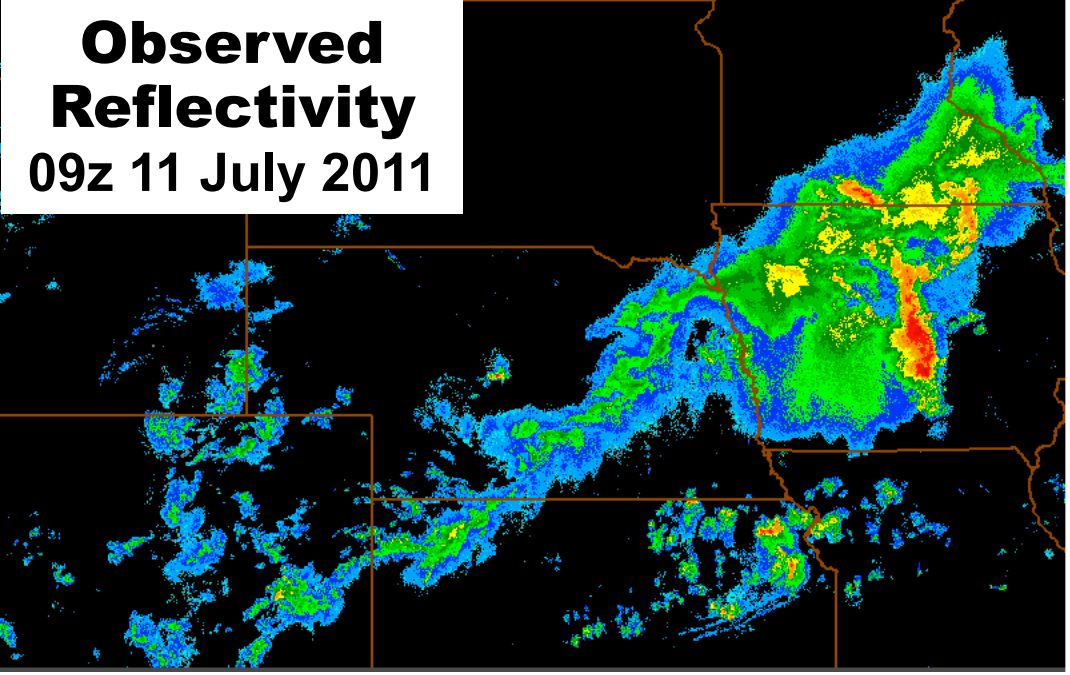


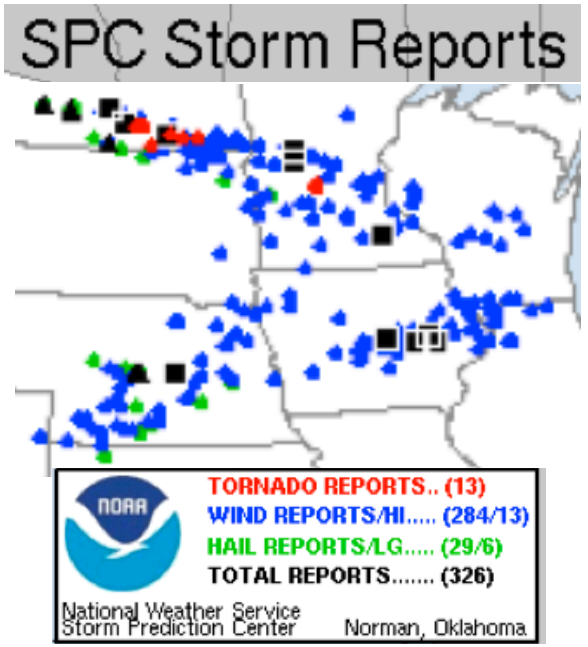


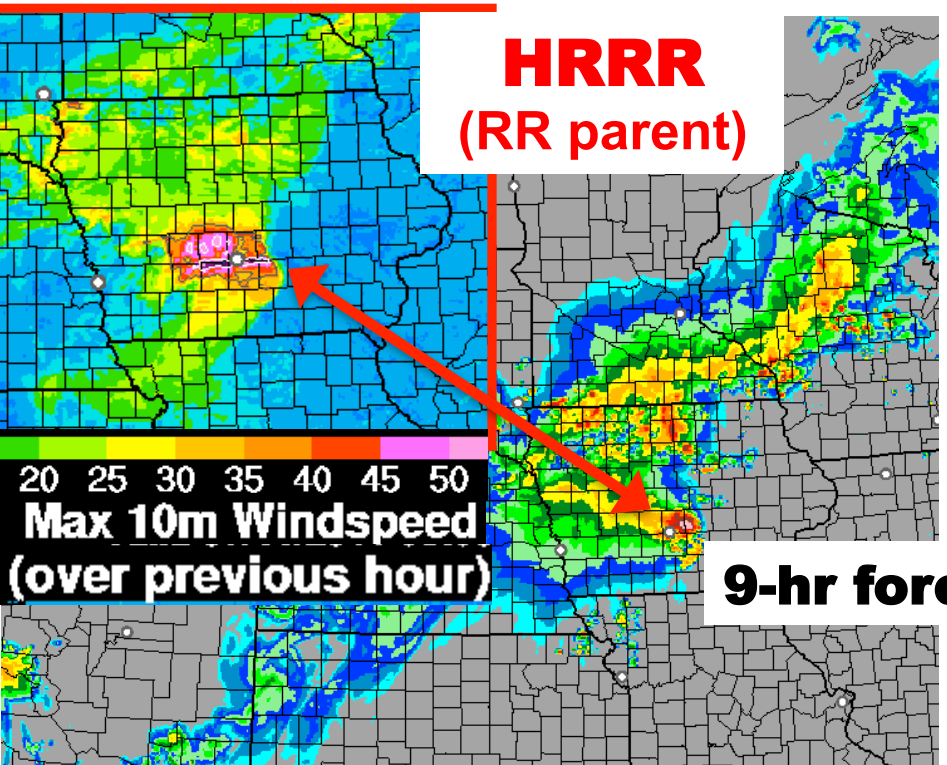


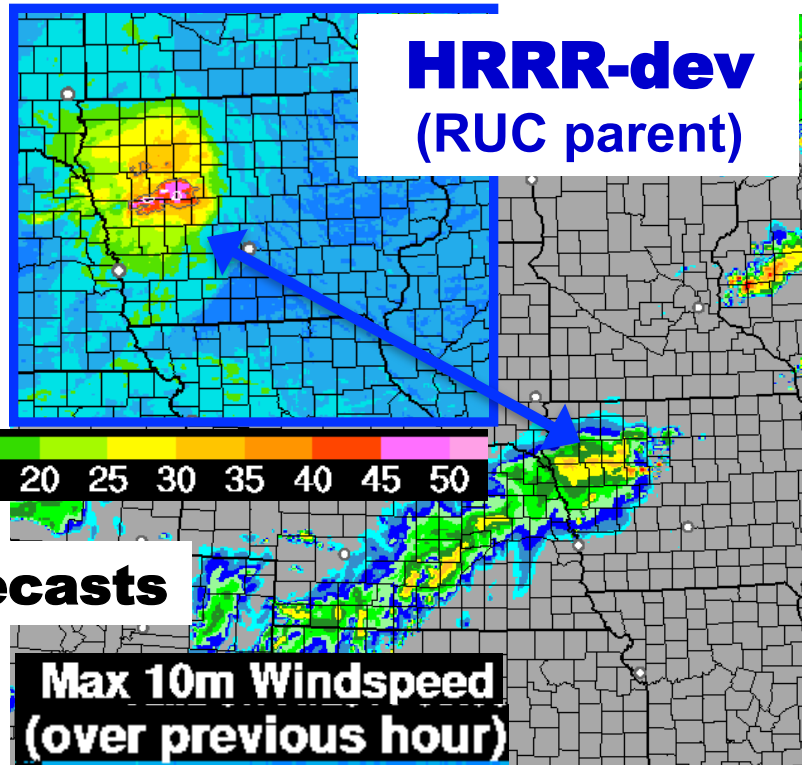


6-hr forecast



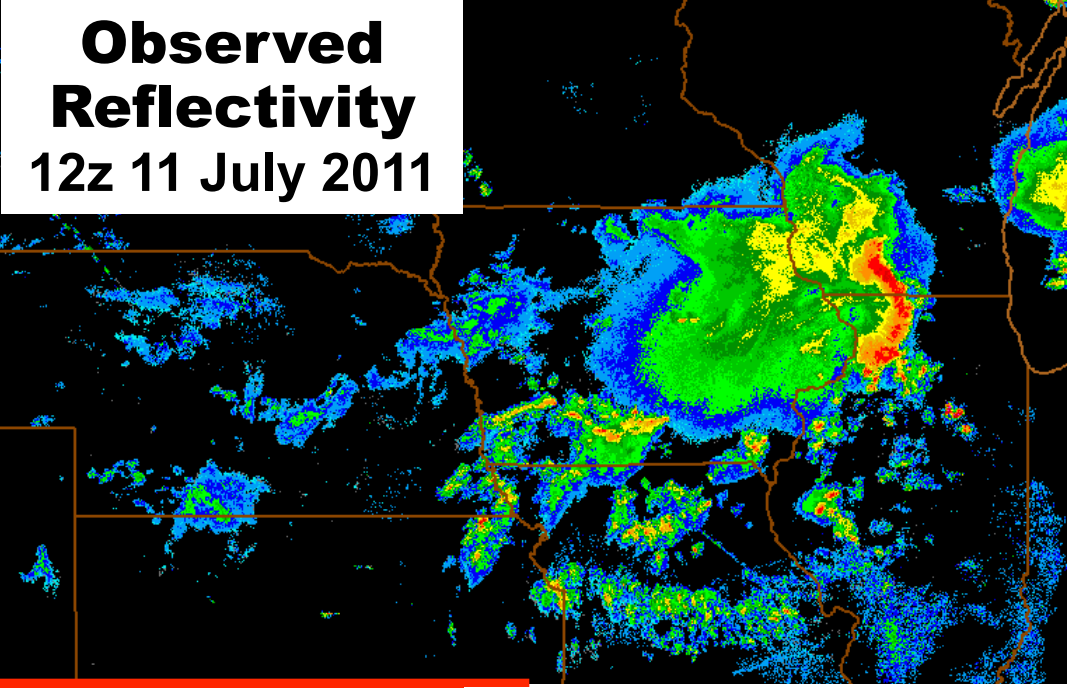


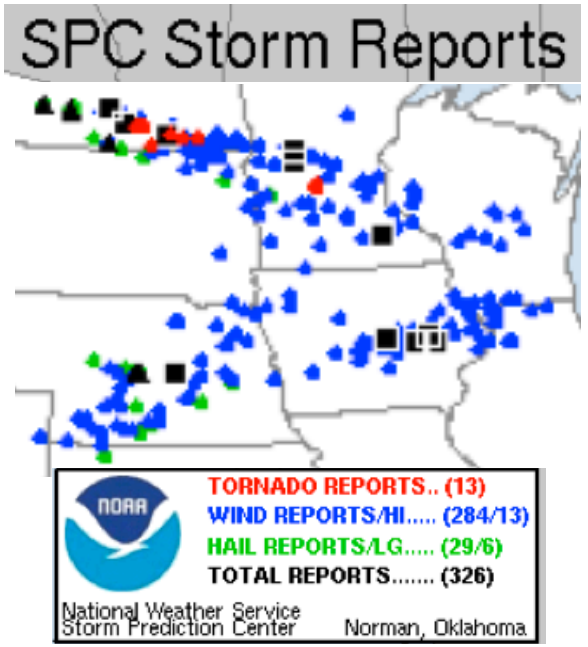




9-hr forecasts

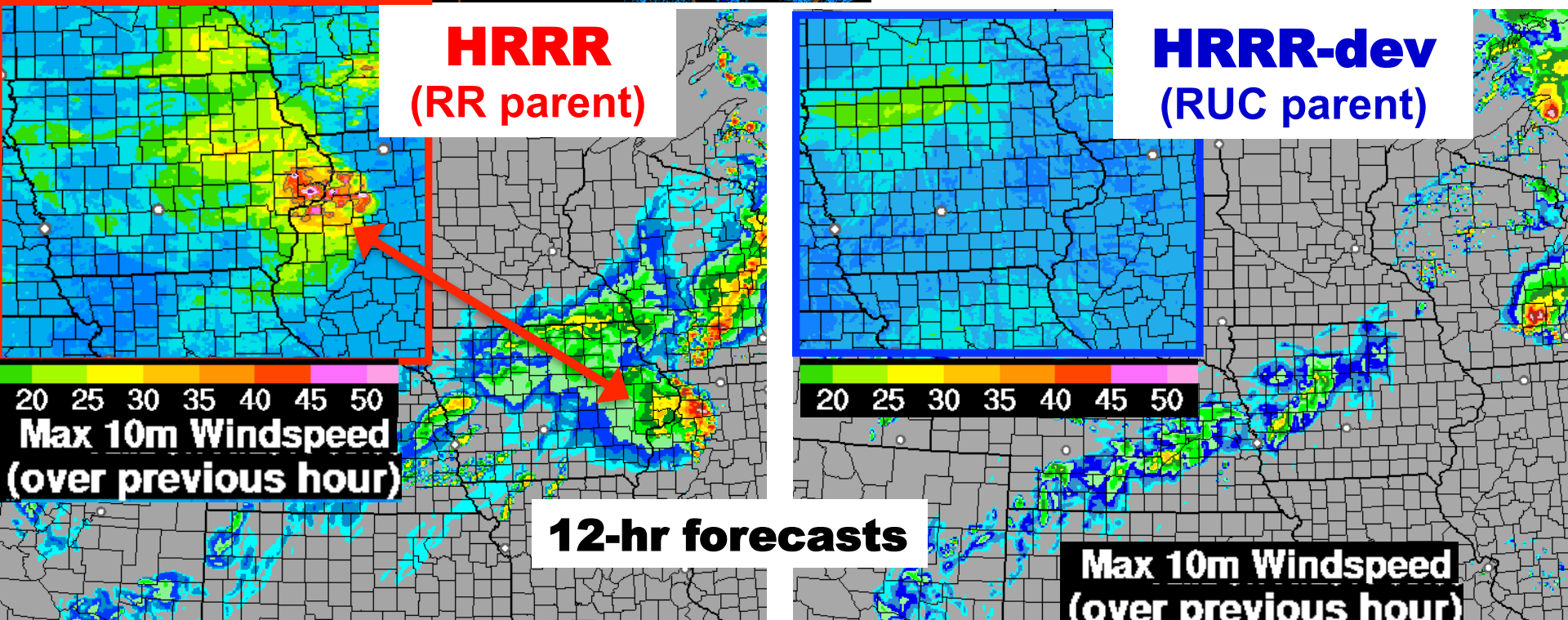
Observed Reflectivity
12z 11 July 2011



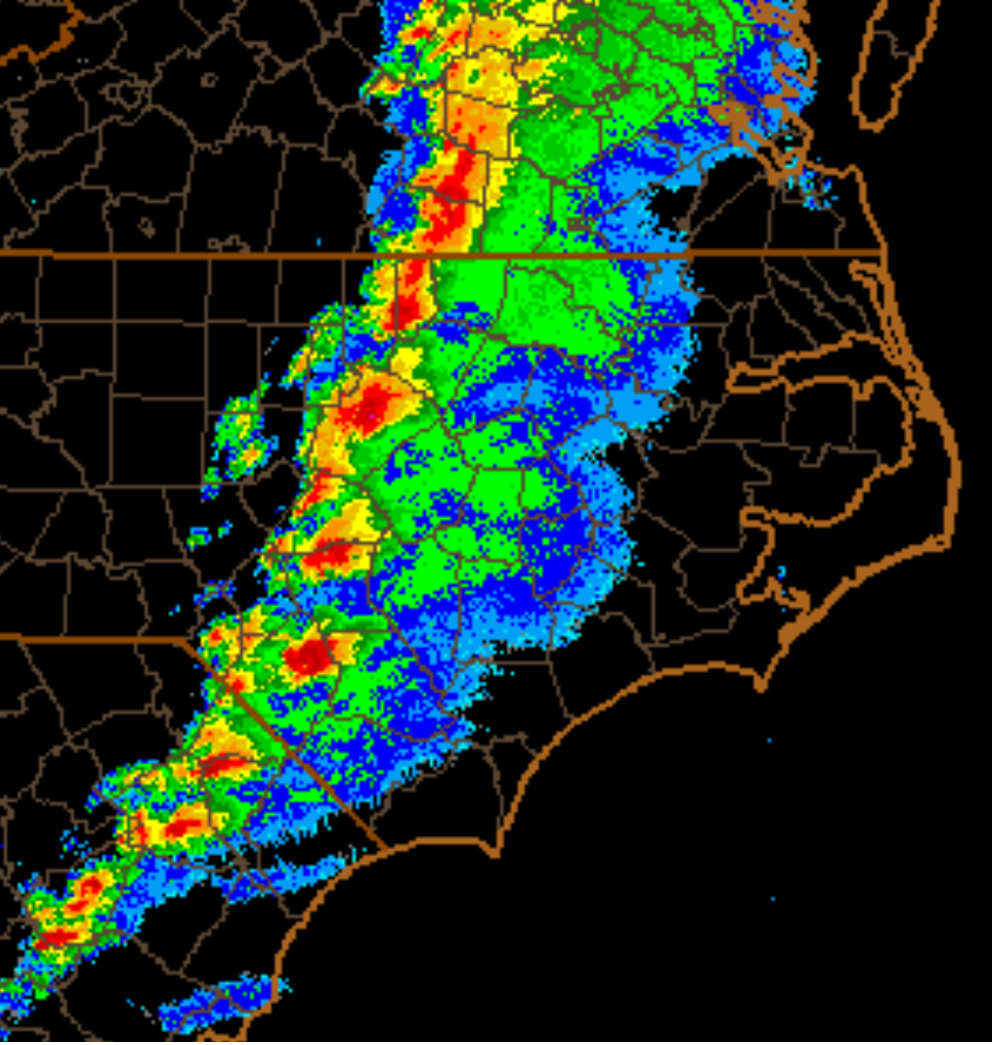


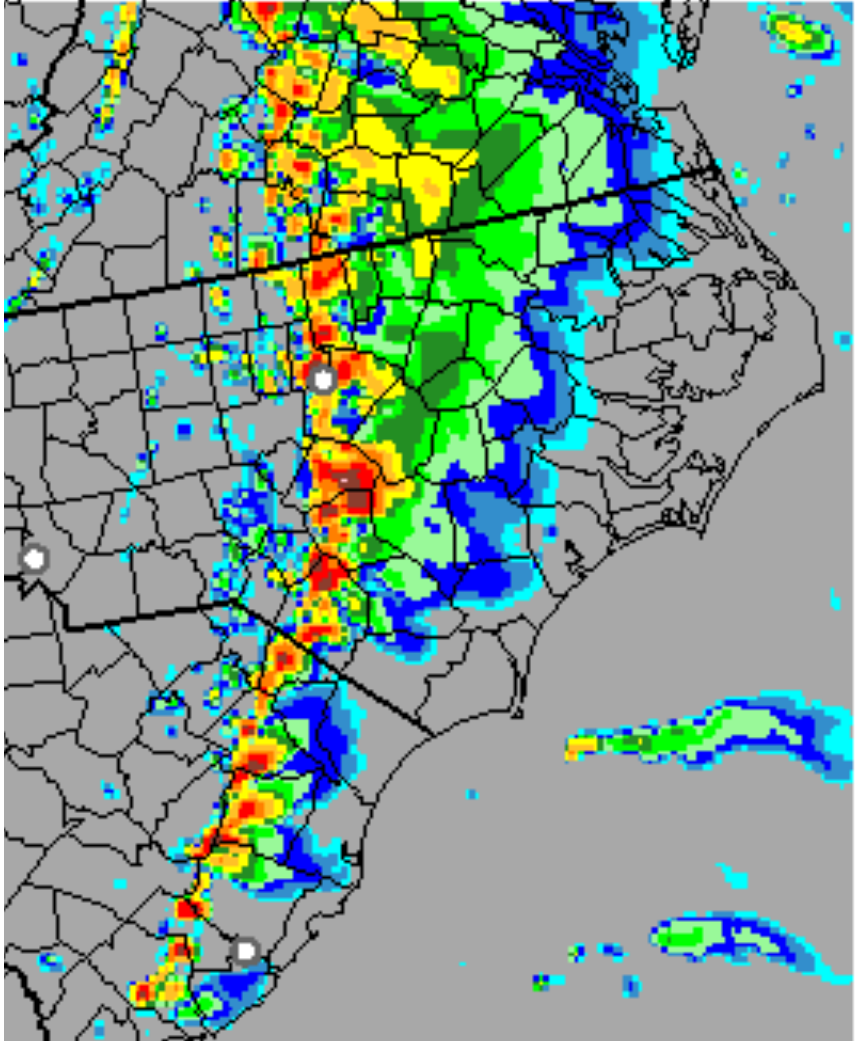
HRRR
(RR parent)

HRRR-dev
(RUC parent)



12-hr forecasts

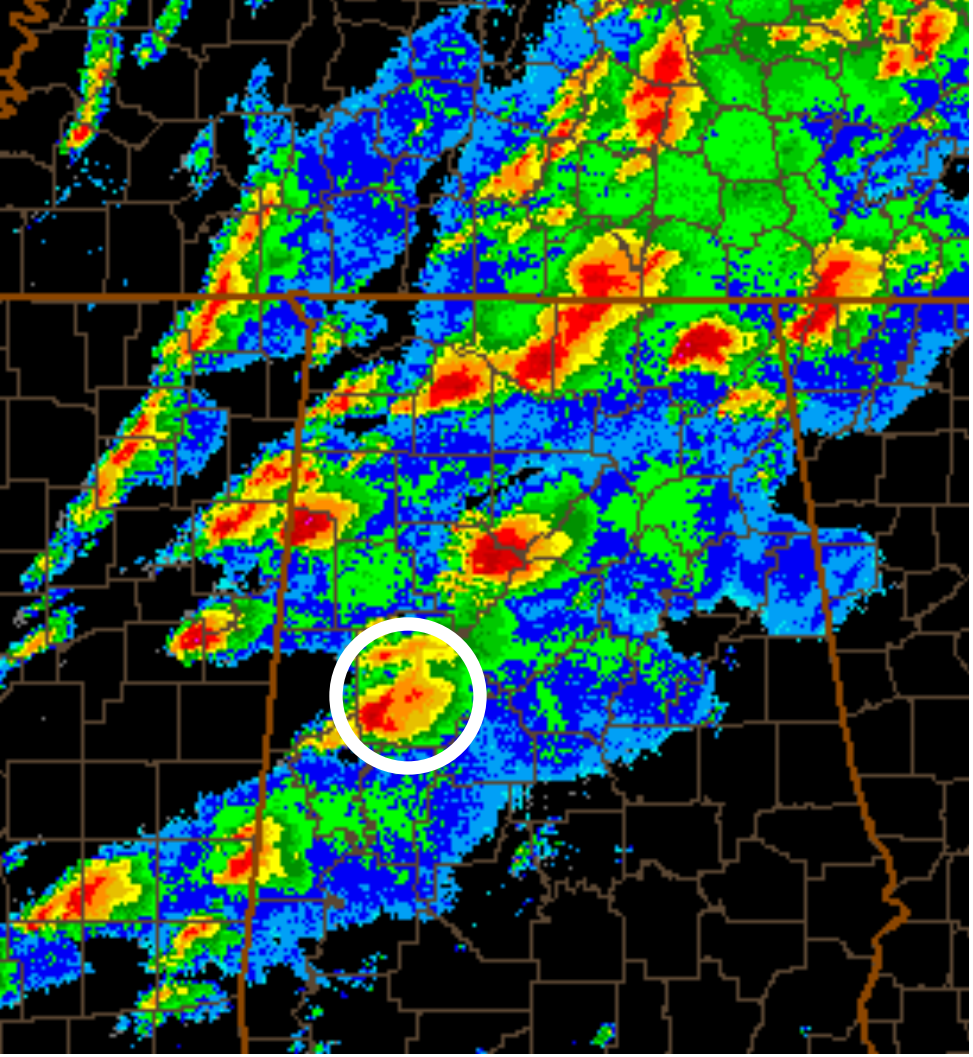


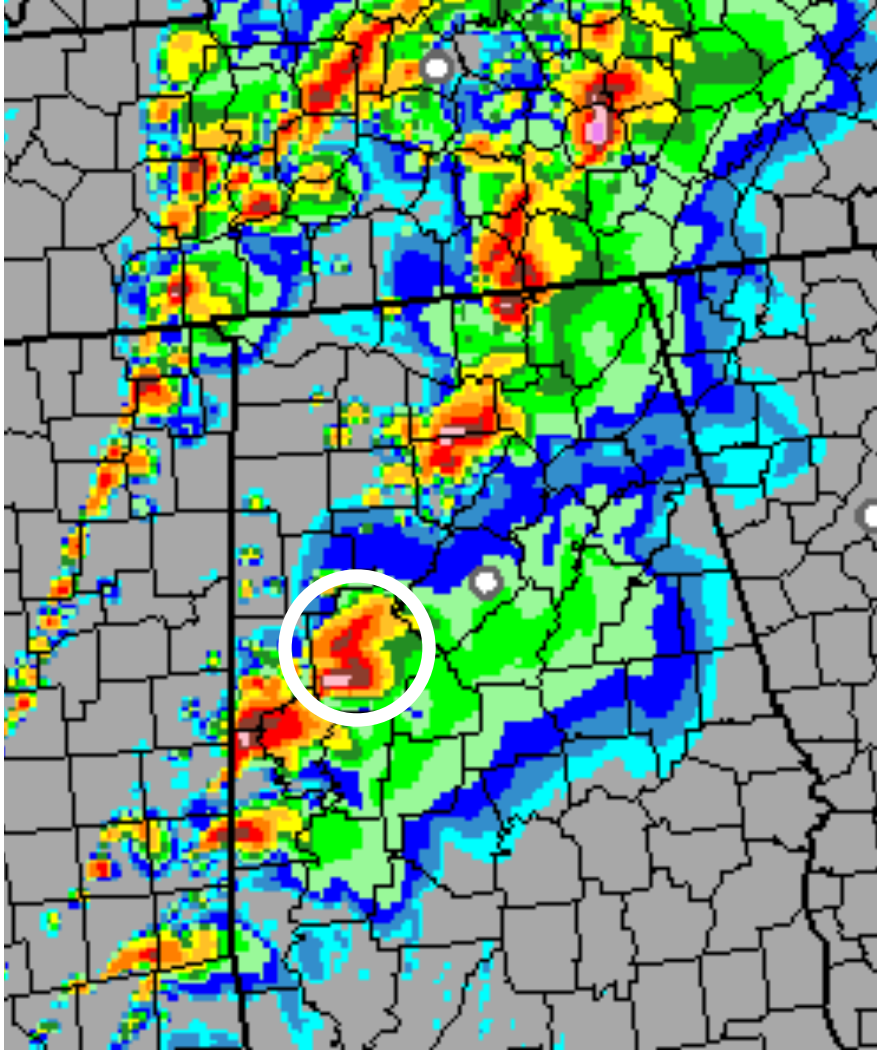


Radar observations

8 hour HRRR model forecast

20 UTC
April 16, 2011

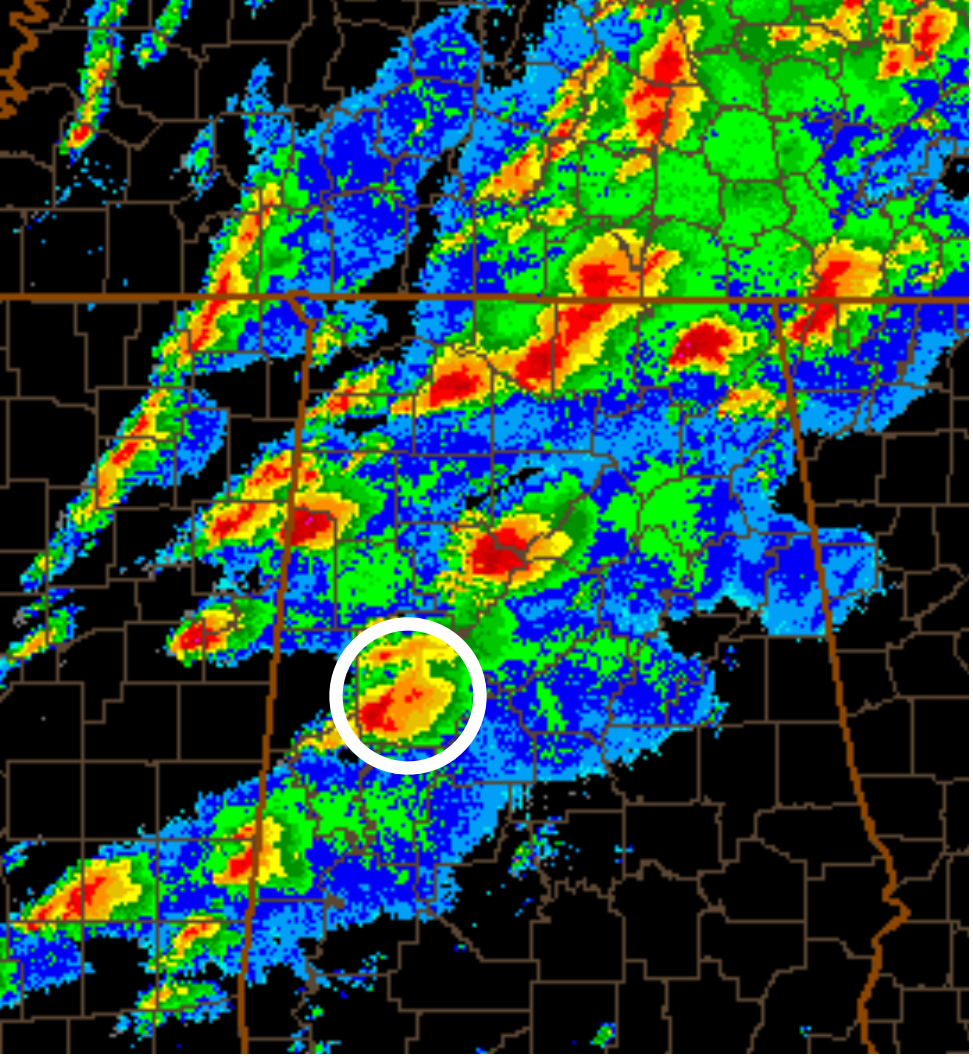


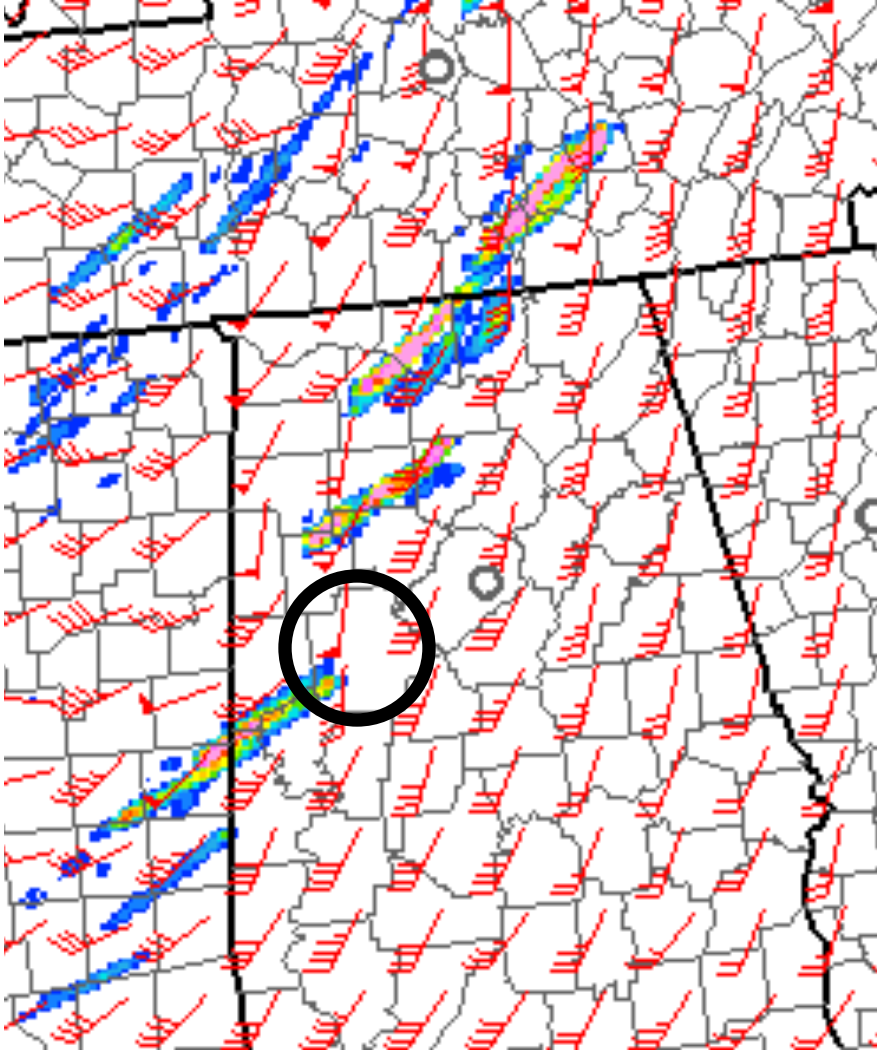


Radar observations

9 hour HRRR model forecast reflectivity

22 UTC
April 27, 2011





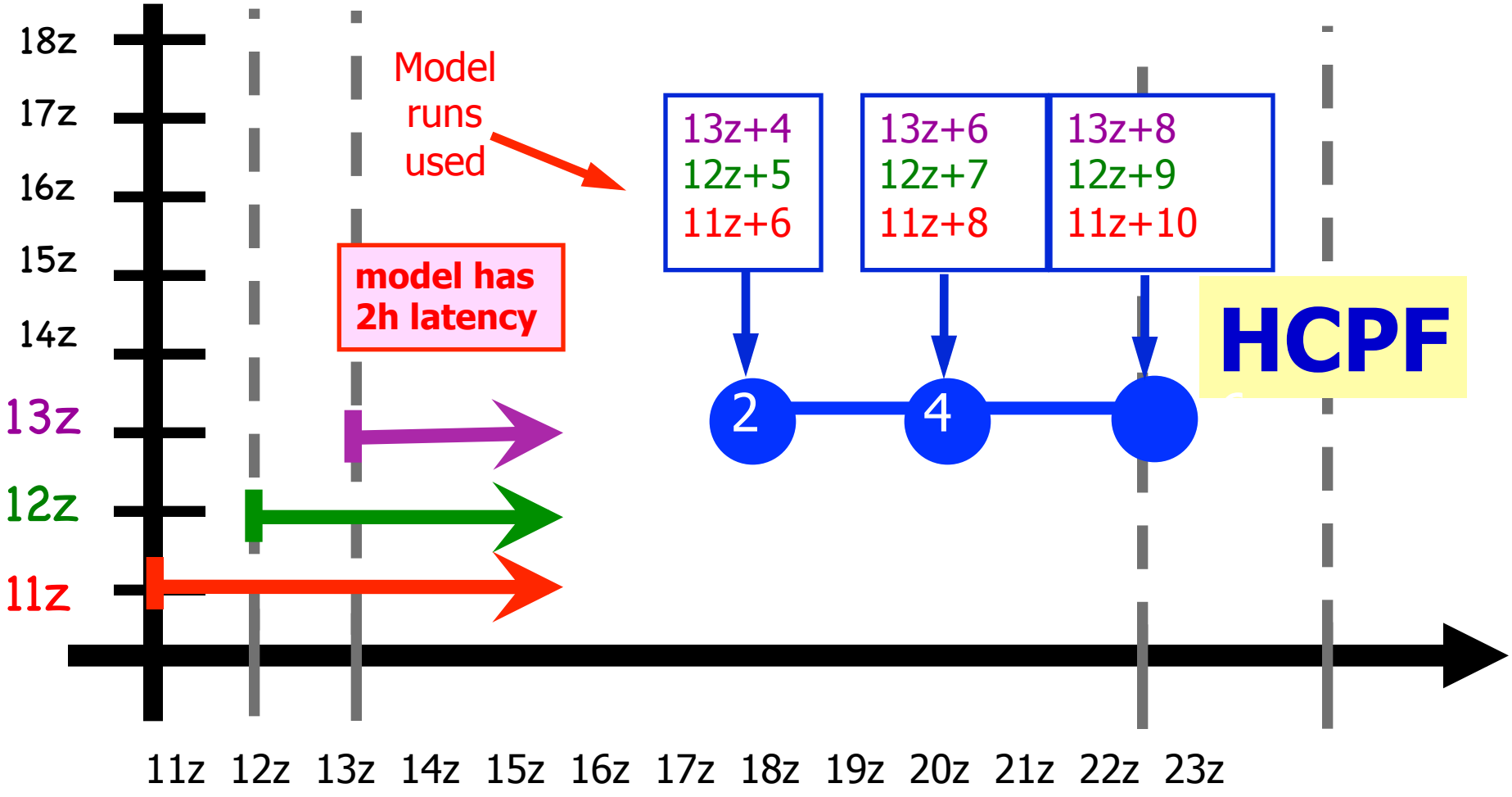
Radar observations

9 hour HRRR model forecast updraft helicity

22 UTC
April 27, 2011

Time-lagged ensemble

Example: 15z + 2, 4, 6 hour HCPF

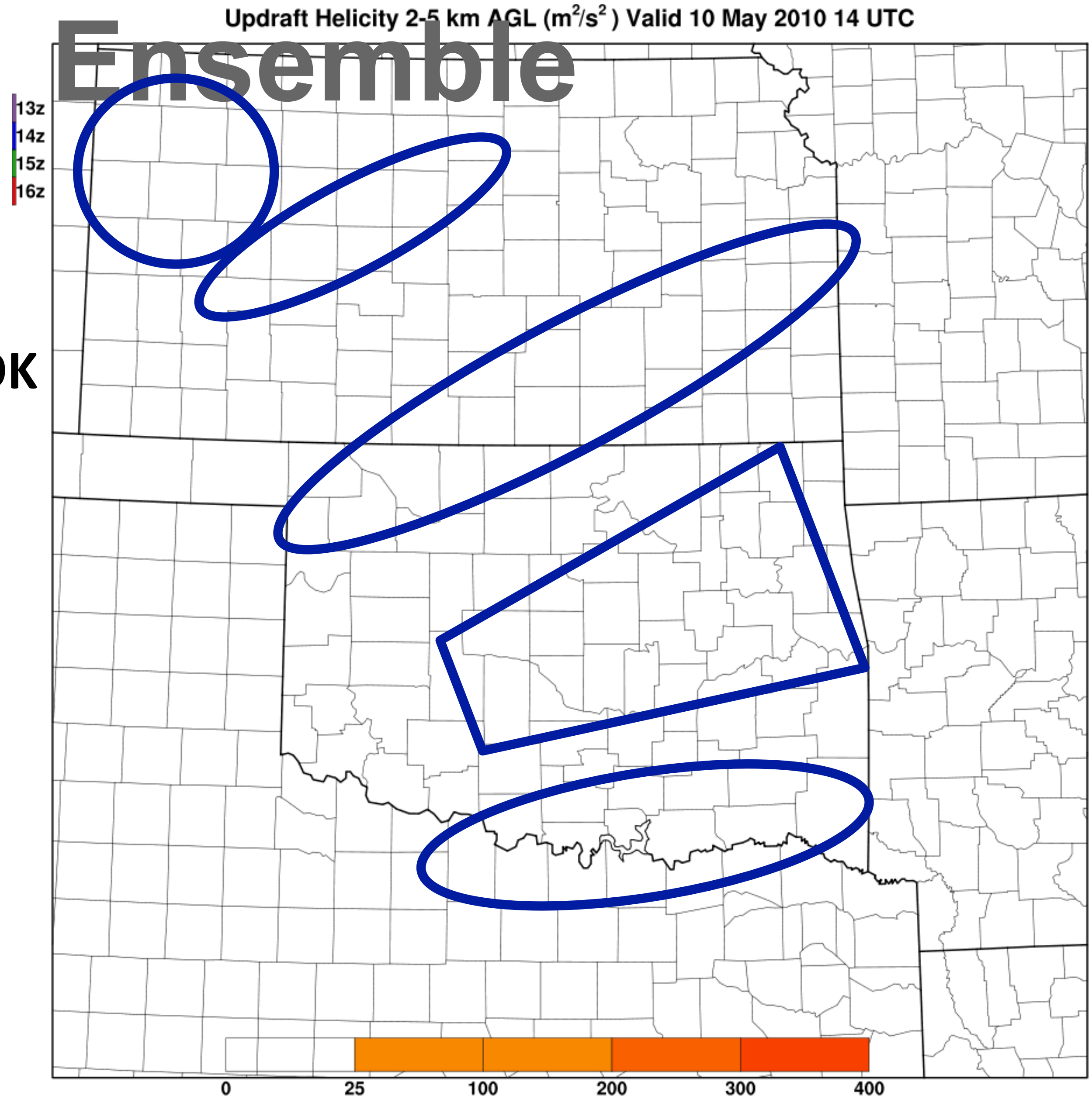


HRRR Time-lagged Ensemble

Severe Weather Application

Tornado Outbreak KS/OK
10 May 2010

Updraft helicity from four HRRR runs 13-16 z
(color-coded by run)



13z HRRR
14z HRRR
15z HRRR
16z HRRR

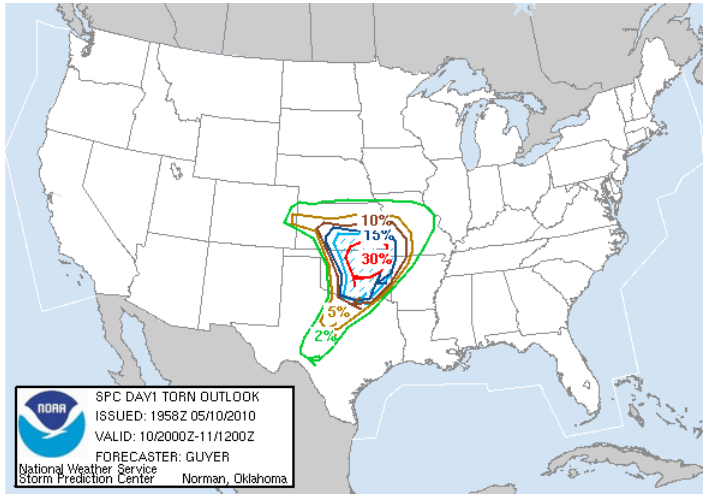
Tornado Reports

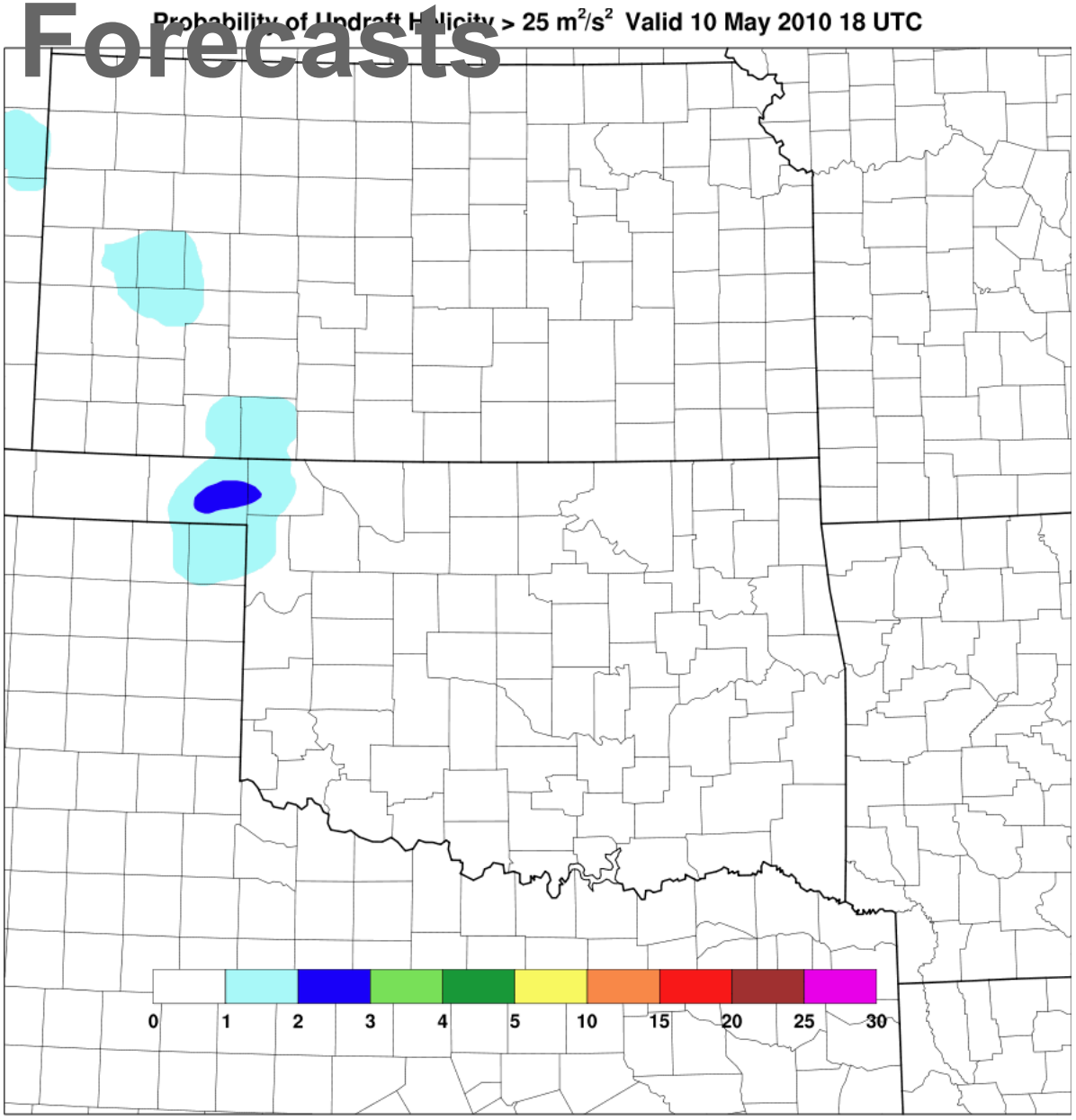
HRRR Severe Weather Forecasts

Tornado Outbreak KS/OK
10 May 2010

Updraft helicity probability
Four consecutive HRRR runs (13-16 UTC)

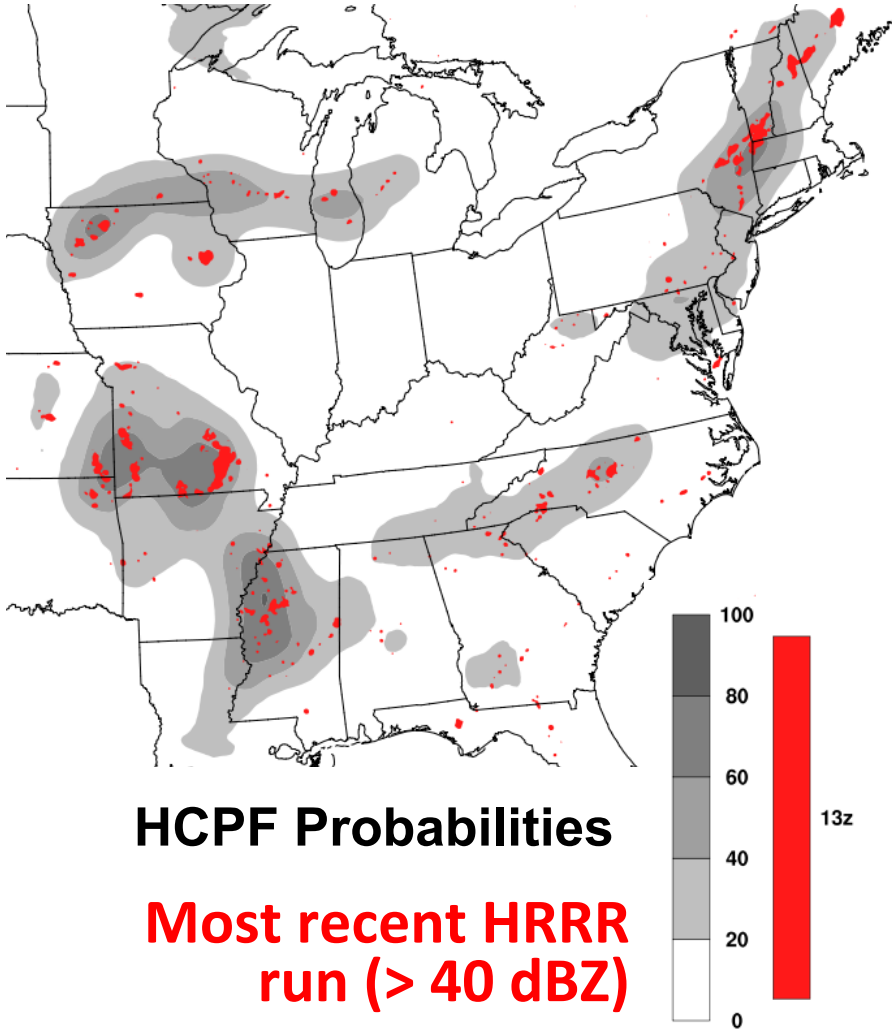
Time-bracket of 2-hrs
45 km search radius





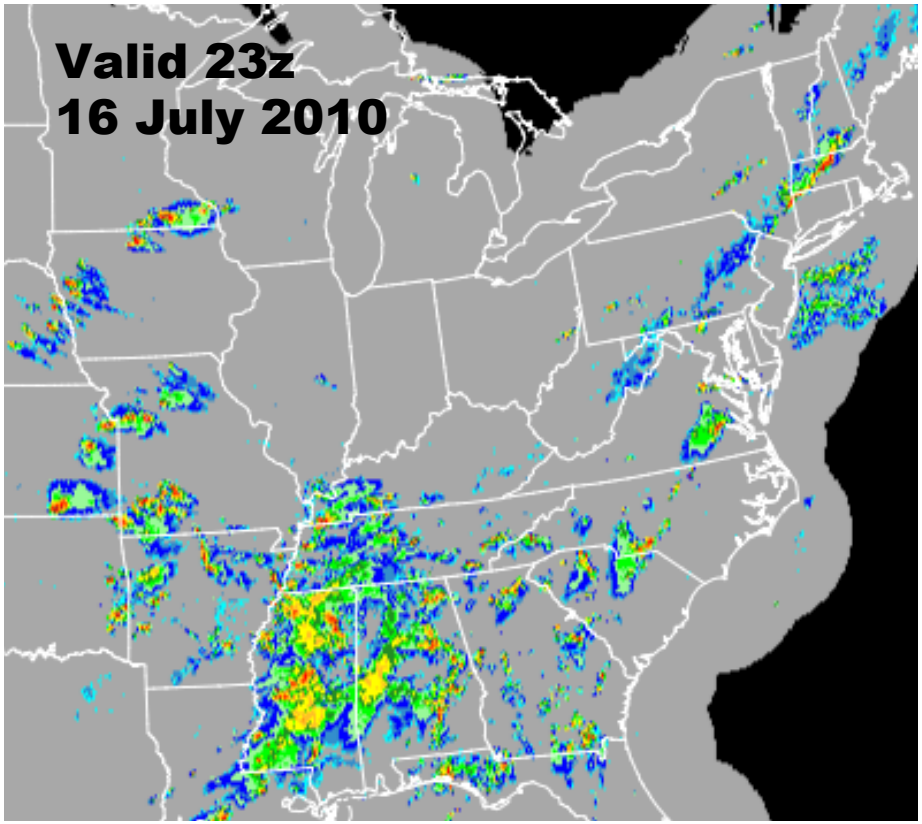
HRRR and HCPF

Overlaying deterministic and probabilistic guidance



HCPF Probabilities

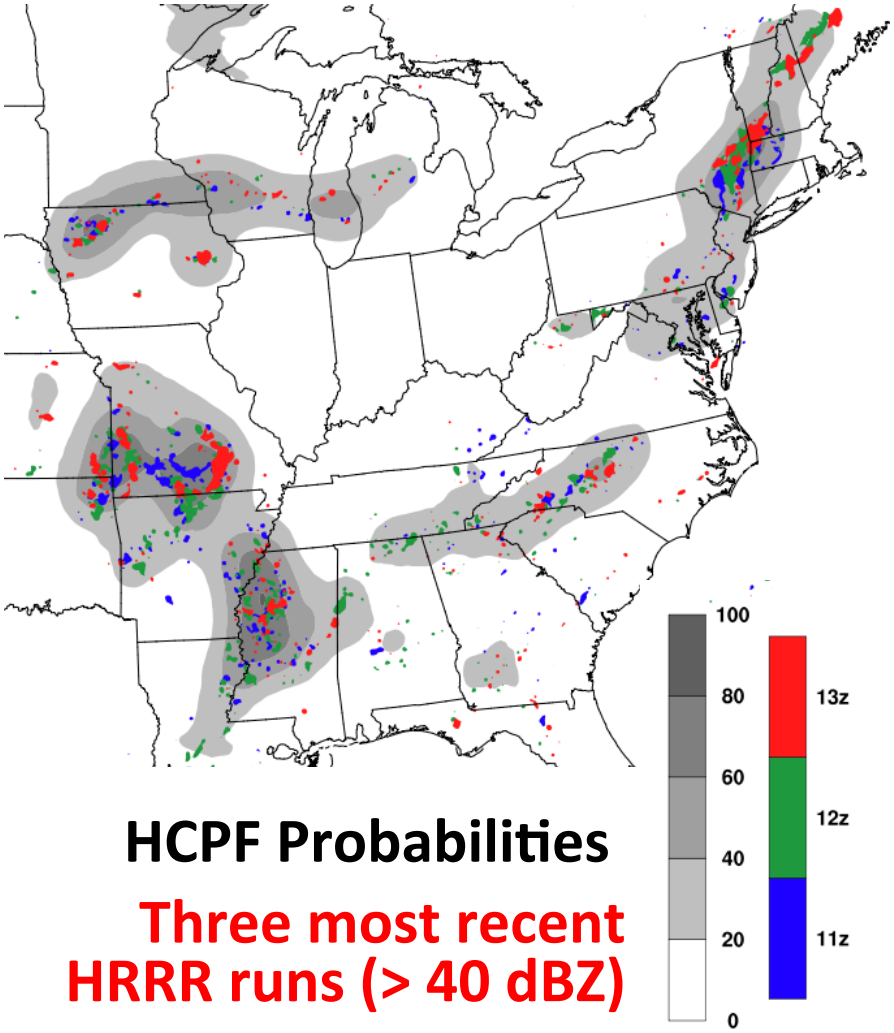
Most recent HRRR run (> 40 dBZ)



Radar Observations

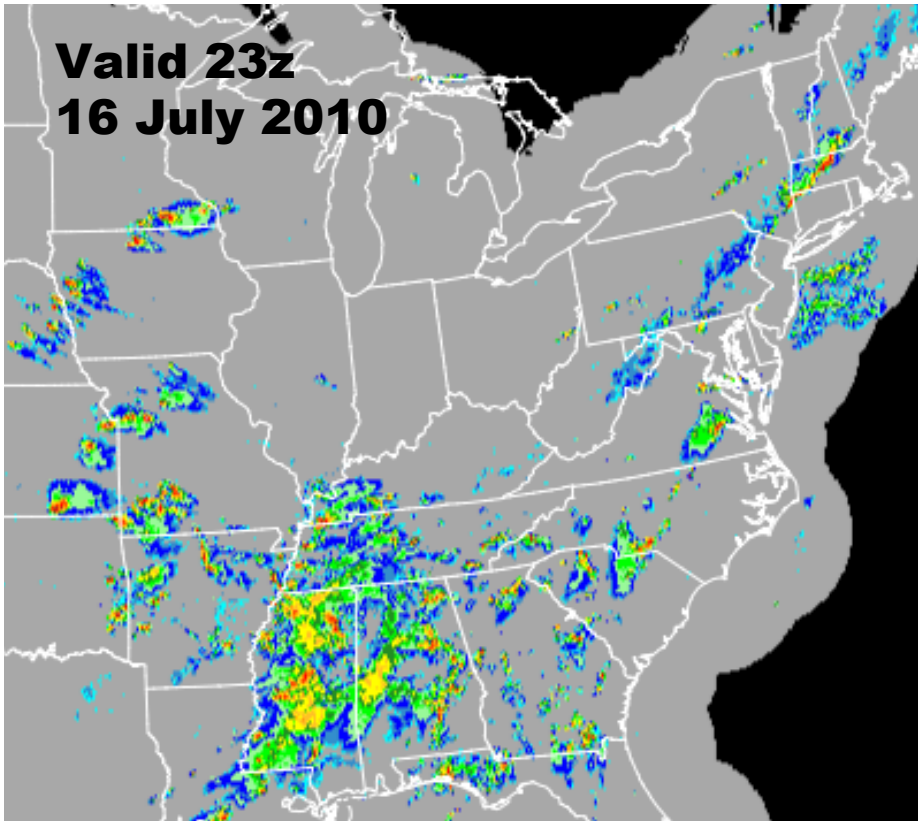
HRRR and HCPF

Overlaying deterministic and probabilistic guidance



HCPF Probabilities

Three most recent HRRR runs (> 40 dBZ)



Radar Observations

15-min output frequency (grib files) available for selected fields

Comparison of HRRR forecast reflectivity
(with 15-min output frequency)
and observed reflectivity for hurricane Irene

Additional HRRR points

- **HRRR useful for much more than convection**
  - → Surface wind forecasts, especially in the west
  - → Terrain related features
  - → Ceiling and visibility forecasts
  - → County-scale details for many systems

- **HRRR skill very dependant on Rapid Refresh**

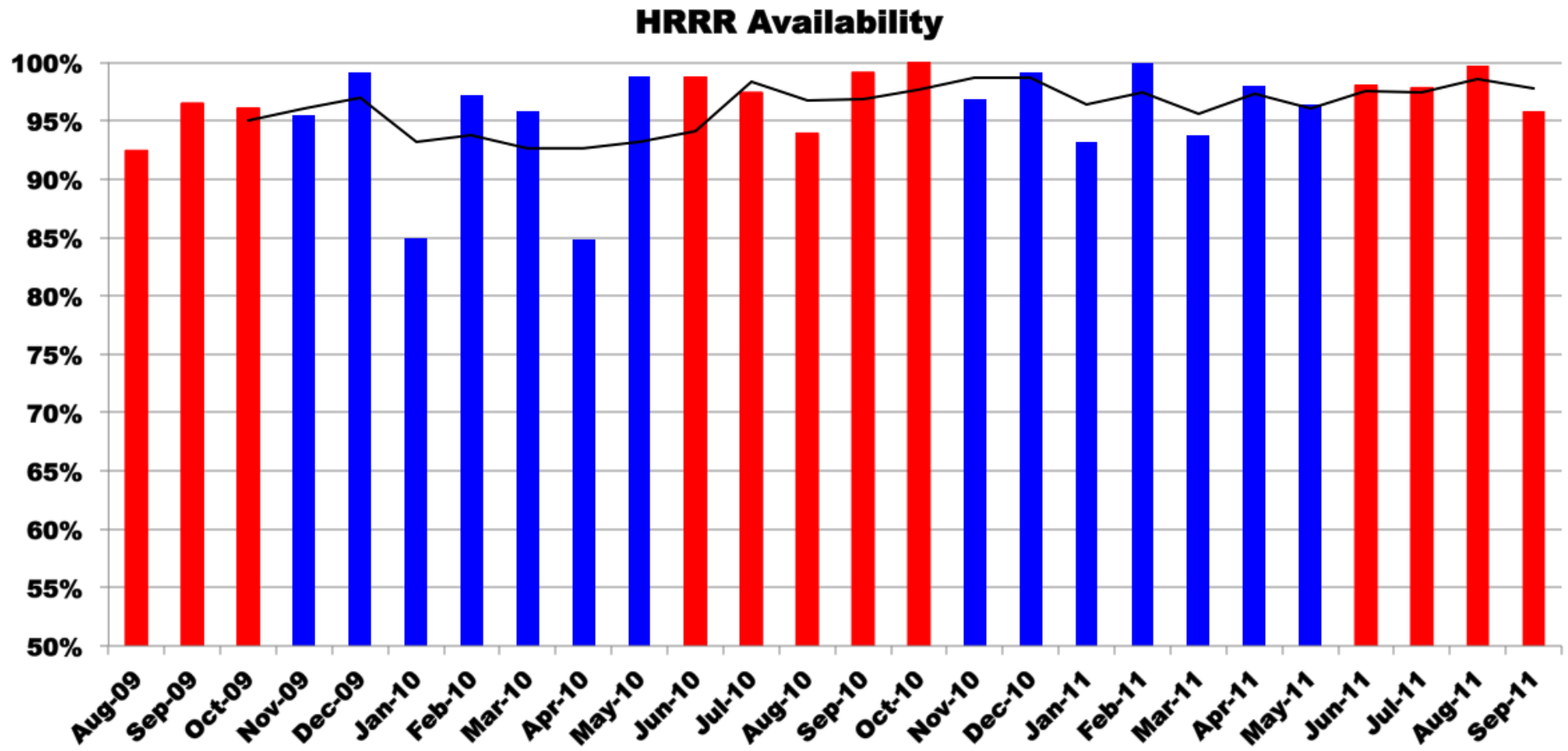
  - → RR hourly assimilation of conventional obs key
  - → RR radar-DFI is HRRR storm DA mechanism
  - → RR Model biases greatly affect HRRR forecasts
  - → **RR improvements in these areas help HRRR**

- **HRRR development work areas**
  - → RR model (WRF-ARW) and data assimilation (GSI)
  - → HRRR model and assimilation
  - → HRRR output post-processing (special fields – NSSL, TL-ensemble probabilities, hourly soundings)

Ongoing / Future HRRR (and RR) work

- **HRRR model changes**
  - → **Update to WRF v3.3.1**
  - → **Switch to 5th order vertical advection**
  - → **Switch to W-Raleigh damping for upper levels**
- **Radial velocity assimilation**
  - → **Slight degradation in last 13-km test, expect for RR2**
  - → **Experiments with 3-km radial velocity assimilation**
- **3-km cloud analysis**
  - → **Test GSI cloud analysis at 3-km with eventual 3-km cycling of cloud / hydrometeor and LSM fields**
- **Regional EnKF / hybrid work with OU/CAPS**
  - → **Excellent progress for coarse resolution (40-km) system**
- **Storm-scale EnKF / hybrid assimilation**
  - → **Collaboration with NSSL Warn On Forecast Project**

HRRR Hourly Reliability (≥ 12 hr forecast)
More Than Three Consecutive Missed/Incomplete Runs



CoSPA Operational Evaluation Periods

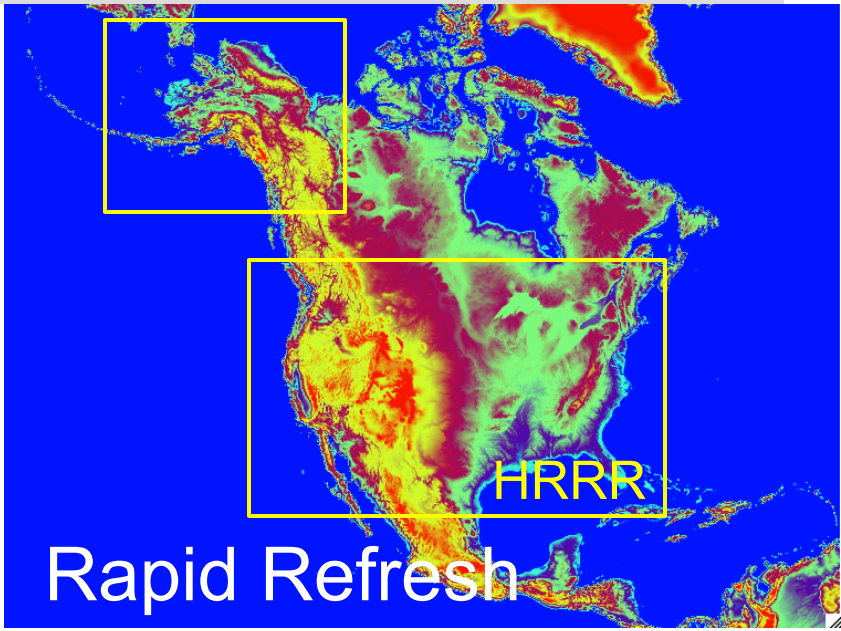
3 month running average

HRRR computer reliability from NOAA

- **Current – 1 computer running HRRR**
  - NOAA/ESRL – Boulder (jet)
  - Current reliability: 97% for last 12h months (allowing up to 3h gaps)
- **2012-14 – 2 computers running HRRR – interim solution**
  - Boulder – computer 1 (jet)
  - Fairmont, WV – computer 2 (zeus) – suggest NCO operations for HRRR on zeus
  - **Reliability goal - 99%**
  - In discussion: Fill in missing HRRR products with hourly 13km Rapid Refresh and 6-hourly 4km NAM-nest
    - lower quality: can't have storm-resolving resolution and hourly updating with radar assimilation outside of the HRRR
- **2015 – NCEP running HRRR**
  - NOAA/NCEP computing budget – will allow no increase before 2015
  - Cost of HRRR – 15-22% (!) of current NCEP computing for all operational models (GFS, NAM, RUC, ensembles)
  - Computing acquisition for NOAA Research (e.g., HRRR processors funded by FAA and NOAA) has been very efficient
- Conclusion***: Interim HRRR computing for 2012-14***

Future plans for advanced hourly NWP/DA

- Jan 2012 – Rapid Refresh operational at NCEP
- Late 2012-early2013 - RapidRefresh2 –
  - cloud/surface/soil assimilation, GOES, sodar/tower/nacelle, updated GSI
  - model – MODIS, cloud/PBL/numerical improvements, updated WRF
- 2013 – application of hybrid/EnKF assimilation to RR in real-time testing
- 2012-14 – HRRR @ESRL improves, add Fairmont HRRR to reach 99%
- 2015 – High-Resolution Rapid Refresh operational at NCEP for CONUS



- 2015 – Ensemble Rapid Refresh – **NARRE** w/ hybrid assi**m**
- 2016 – Add operational Alaska HRRR
- 2017 – CONUS Ensemble HRRR – **HRRRE**

N.American Rapid Refresh Ensemble

- **NEMS-based NMM, ARW cores**
- **Hourly updating with GSI-hybrid EnKF**
- **Initially 6 members, 3 each core, physics diversity (RR, NAM, NCAR suites)**
- **Forecasts to 24-h**
- **NMM to 84-h 4x per day**

Other improvements in init testing

- Add inline chem, chem DA
- 15-min radar assimilation
- Storm-scale radar assimilation